INVESTIGATION OF HYDROFLAPS FOR STEERING SEAPLANES

MASTER OF SCIENCE THESIS
BY
PRESTON ELLSWORTH BECK

Thesis
B33

Experimental Towing Tank
Stevens Institute of Technology
Hoboken, New Jersey

June, 195

THESIS
B33

Library
U. S. Naval Postgraduate School
Monterey, California

A N I N V E S T I G A T I O N O F H Y D R O F L A P S F O R S T E E R I N G S E A P L A N E S

A Thesis Submitted in Partial Fulfillment

of the Requirements for the Degree of

Master of Science

STEVENS INSTITUTE OF TECHNOLOGY

Submitted by Preston Ellsworth Beck

TABLE OF CONTENTS

17319

SUMMARY

This report furnishes the design data for the hydrodynamic proportioning of hydroflaps as used for the control of flying boats in taxiing. The hydroflap has been found to require an area of approximately 0.6 sq.ft. to give a yawing moment equivalent to that produced by a fully submerged rudder with an area of 1 sq.ft.

The investigation of this device consisted of a mathematical analysis and of tank tests on a model hull. The mathematical approach yielded an equation for predicting the magnitudes of the moments produced by opening of one flap. The equation was written in terms of a proportionality constant, the moment arm and the geometric angles involved. Through comparison of experimental and theoretical data the normal force coefficient in the proportionality constant was found to have a mean value of two for the range of the tests.

The optimum values of the hinge angle and the angle of opening of the flap were found to be about 35° and 70° respectively. There was only one model available so the effect of variation of the afterbody deadrise was only investigated analytically. A critical value of the hinge angle was found at about 40°, above which the yawing moments diminished rapidly.

The experimental tests were conducted in Tank 1 of the Experimental Towing Tank, Stevens Institute of Technology, Hoboken, New Jersey.

INTRODUCTION

The maneuvering of flying boats while taxiing on the water has always been difficult. Although many devices for maneuvering have been used or tested a simple and efficient method has not been perfected. The problems involved are discussed in great detail by Libbey (1) and other researchers (2,3,4,5) and will not be repeated here.

At this time one of the more promising solutions to the problem appears to be hydroflaps. Hydroflaps, sometimes referred to as differential spoilers, are flat plates located on each side of the afterbody bottom of the hull of the seaplane ahead of the sternpost as shown in Fig. 5. The plates are flush with the bottom when closed and can be opened up in a manner similar to the conventional wing flaps or divebrakes used on aircraft. The flaps can be operated together for braking action or individually to produce yawing moments.

This system has several very desirable features. The flaps do not require a complex operating system such as exists with reverse pitch propellers. When not in use they are retracted flush with the bottom and thus are completely out of the way and will not interfere with other operations. Equally important, substantial yawing moments can be obtained and at the same time the velocity of the seaplane is reduced by the increase in drag. The latter item becomes more important as the size of the seaplane is increased. A further advantage

is that simultaneous opening of both flaps provides braking action so the system has a dual purpose.

The undesirable feature of hydroflaps is the structural problem that is introduced. The installation requires cutting into the basic structure of the hull and furthermore the loads on the open flap are very high. This means that the designer has to provide a structurally strong flap and operating system and at the same time not permit it to compromise the strength of the hull.

An expression was derived herein for estimating the static yawing moments produced by one hydroflap, when opened, in terms of afterbody deadrise, hinge angle, angle of opening and a proportionality constant. Tank tests were conducted on a model fitted with hydroflaps and the proportionality constants were determined for the conditions tested by comparison of the analytic and experimental data.

The effect of variation of the geometric parameters was investigated to determine the optimum values for producing yawing moments.

This discussion has been limited to the study of yaw. The problems of pitch and braking action have been considered by Feuerbach (6). The tank tests for both studies were run simultaneously and all the data recorded is contained in tables in both of the reports.

The tank tests were performed in Tank 1 of the Experi-

mental Towing Tank, Stevens Institute of Technology, Hoboken, New Jersey in February through April 1951.

Acknowledgment is made to the many people on the staff of the Experimental Towing Tank who aided the project. Particular appreciation is given to Professor B.V. Korvin-Kroukovsky for his advice and many suggestions.

SYMBOLS

Miscellaneous

b	Beam, ft.
C	Coefficient
g	Acceleration of gravity, 32.2 ft./sec.^{2}
L	Moment arm, ft.
M	Moment, ft.lbs.
m	Model
$f\ s$	Full scale
$\frac{1}{2}\rho V^2$	Dynamic pressure, lb./sq.ft.
V	Velocity, ft./sec.
V_o	Takeoff velocity, ft./sec., where $\Delta = 0$
A	Area, sq.ft.
w	Specific weight of fresh water, 62.4 lb./ft.^{3}
Δ	Load on water, lb.
Δ_o	Gross weight, lb.
λ	Scale ratio of model to full size
p	Port side
s	Starboard side
ρ_a	Density of air, 0.002378 slug/ft.^{3}
ρ	Density of water, 1.94 slug/ft.^{3}
$c\ g$	Center of gravity

Angles

Ω	Angle of opening of hydroflap measured from afterbody keel, deg.

α	Angle of opening of hydroflap measured from afterbody bottom, deg.
β	Deadrise, deg.
σ	Sternpost angle, deg.
τ	Trim angle, deg.
ϕ	Heel angle, deg.
ψ	Yaw angle, deg.
θ	Hinge angle, deg.

Non-dimensional Coefficients

$C_\Delta = \Delta/wb^3$	Load coefficient
$C_V = V/(gb)^{1/2}$	Speed coefficient
$C_{M_\psi} = M_\psi/wb^4$	Yawing moment coefficient
$C_L = W/\frac{1}{2}\rho V^2 A$	Lift coefficient
k	Normal force coefficient

FORCES ON OPEN HYDROFLAP-MATHEMATICAL ANALYSIS

Presented here is the derivation of an analytical expression for approximating the static yawing moments produced by opening of one hydroflap. Only the forces on the flap are considered although in reality the yawing moment is increased by the pressure of the water (piled up by the flap) on the side and bottom of the hull. This effect is subsequently accounted for by introduction of a factor k. The value of k was determined for the hull tested on the basis of comparison of the computed and the experimental data.

The following assumptions were made:

(a) The hydroflap is completely immersed (low velocity).

(b) The flow of the water is essentially parallel to the keel of the afterbody bottom.

(c) The resultant force vector is perpendicular to the plane of the hydroflap (frictional drag component small enough to neglect).

(d) Free water surface effects can be neglected.

(e) Forces on the flap are proportional to the sine of the angle between the flow and the surface of the flap.

(f) The resultant force vector acts through the point of intersection of the flap hinge line with the afterbody keel (point O on Fig. 1). The error introduced is small since the movement of the force vector is small compared to the magnitude of the moment arm.

The following nomenclature was used in Fig. 1:

(A) β = angle $-$YOC = angle of deadrise measured in the YZ plane,

θ = angle $-$XOY" = hinge angle,

α = angle DOD' = angle between the planes of the afterbody bottom and the hydroflap.

(B) EF = hinge line. The hinge line extended to intersect the chine at C and the keel at O.

(C) O is the origin of the XYZ coordinate system where the XZ axes form the plane of symmetry. The chine was drawn parallel to the keel, its position being determined by the point C.

(D) The airplane is moving in the direction of the +X axis.

(E) e = arbitrary distance from the plane of the bottom measured along a perpendicular to that plane.

PART A

Equation of the plane of the afterbody bottom, DEFG. The normal form of the equation of a plane (7) is:

$$x \text{ Cos } A + y \text{ Cos } B + z \text{ Cos } C = p \text{ .}$$

In this case:

$$p = 0 \qquad\qquad A = 90^\circ$$

$$\text{Cos } B = \text{Cos } (90 - \beta) = \text{Sin } \beta$$

$$\text{Cos } C = \text{Cos } \beta \text{ .}$$

The equation of the plane becomes:

$$x\ (0) + y \text{ Sin } \beta + z \text{ Cos } \beta = 0.$$

PART B

Equation of the plane containing the hydroflap. The equation of a plane passing through three given points:

$$\begin{vmatrix} x & y & z & 1 \\ x_1 & y_1 & z_1 & 1 \\ x_2 & y_2 & z_2 & 1 \\ x_3 & y_3 & z_3 & 1 \end{vmatrix} = 0$$

The coordinates of the point O are (0,0,0). By geometry the point C has the coordinates

$$-x = OC \operatorname{Cos} \theta$$

$$-y = OC \operatorname{Sin}\theta \operatorname{Cos}\beta$$

$$z = OC \operatorname{Sin}\theta \operatorname{Sin}\beta$$

The coordinates of the point W':

1. Select a point W' in the plane of the hydroflap (open position) as shown in the auxiliary views on Fig. 1.

$x'' = -e \operatorname{Cos} \alpha$

$y'' = 0$

$z'' = -e \operatorname{Sin} \alpha$

where e is an arbitrary length such as one unit of measure.

2. Using the standard form for rotation of an axes system (7):

Rotation about the Z'' axis:

$x = (-e \operatorname{Cos}\alpha) \operatorname{Cos}(90 - \theta) = -e \operatorname{Cos}\alpha \operatorname{Sin}\theta$

$y''' = e \operatorname{Cos}\alpha \operatorname{Cos}\theta$

Rotation about the x axis:

$y = -e \text{ Sin}\alpha \text{ Sin}\beta + e \text{ Cos}\alpha \text{ Cos}\theta \text{ Cos}\beta$

$z = -e \text{ Sin}\alpha \text{ Cos}\beta - e \text{ Cos}\alpha \text{ Cos}\theta \text{ Sin}\beta .$

Substitution into the determinate gives for the final equation:

$$0 = x \text{Sin}\theta \text{ Sin}\alpha - y(\text{Sin}\alpha \text{ Cos}\beta \text{ Cos}\theta + \text{Sin}\beta \text{ Cos}\alpha) + z(\text{Sin}\alpha \text{ Sin}\beta \text{ Cos}\theta - \text{Cos}\alpha \text{ Cos}\beta).$$

PART C

The force vector, F, can be written directly since the coefficients of x,y, and z in the equation of a plane are the direction numbers of a line perpendicular to that plane. The symmetric form of the equation of a line passing through a given point (x_1, y_1, z_1) with the direction numbers a, b, and c is:

$$\frac{x - x_1}{a} = \frac{y - y_1}{b} = \frac{z - z_1}{c} .$$

Thus the equation of the line containing the force vector is:

$$\frac{x}{\text{Sin}\theta \text{ Sin}\alpha} = \frac{y}{-\text{Cos}\theta \text{ Sin}\alpha \text{ Cos}\beta - \text{Cos}\alpha \text{ Sin}\beta} = \frac{z}{\text{Sin}\alpha \text{ Sin}\beta \text{Cos}\theta - \text{Cos}\alpha \text{ Cos}\beta}$$

PART D

The vector form of the equation of the line containing the force vector is:

$\bar{F} = \bar{i} \text{ Cos } A + \bar{j} \text{ Cos } B + \bar{k} \text{ Cos } C.$

An analytic equation can be changed to the normal form by dividing by the square root of the sum of the squares of the coefficients. In this case this quantity is equal to one

so we already have the normal form. This gives:

$$\text{Cos } B = -(\text{Cos}\,\theta \ \text{Sin}\,\alpha \ \text{Cos}\,\beta + \text{Cos}\,\alpha \ \text{Sin}\,\beta).$$

Here the $\bar{k}$ component is not used since the discussion is limited to yaw. The $\bar{i}$ component is neglected since in the assumptions it is considered to act along the keel and thus does not produce a moment.

PART E

It was assumed that the force on the hydroflap is proportional to the sine of the angle of opening of the flap with respect to the flow of the water. The flow of the water was assumed parallel to the afterbody keel giving an angle of opening with respect to the flow of Ω. The angle, Ω, is found by dropping a perpendicular from a given point on the -x axis to the plane of the hydroflap. Determination of the distance from the point to the plane defines two sides of the triangle, from which the angle can be calculated.

The coordinates of the chosen point are (-1,0,0). The distance, d, is found by substituting the coordinates of the point into the normal form of the equation of the plane. Thus $d = \pm \text{Sin}\,\theta \,\text{Sin}\,\alpha$. Sin Ω gives the component perpendicular to the face of the hydroflap and is equal to $\pm \text{Sin}\,\theta \ \text{Sin}\,\alpha$. For opening of the port hydroflap d was taken as positive and is negative for opening of the starboard flap.

PART F

The yawing moment equation for opening of one hydroflap

can now be written as:

$$M_\psi = KL \sin\Omega \cos B$$

$$= \pm KL \sin\theta \sin\alpha [\cos\theta \sin\alpha \cos\beta + \cos\alpha \sin\beta]$$

As used here $K = k(\frac{1}{2}\rho V^2)A$ and so has the dimensions of force (lb.) where k is a non-dimensional multiplier which can be defined as the coefficient of normal force. By comparison of the results of the above equation with experimental data (Figs. 19, 20 and 21) the value of k was determined for the velocities at which tank tests were made. These values are given in Figs. 22 and 23.

The theoretical values of C_{M_ψ}/KL for the model tested, were calculated using the above equation. Plots of the results are given in Figs. 6, 7 and 8. These graphs show the effect of variation of the three parameters α, β and θ. The negative sign indicates yaw to port for opening of the port flap.

The yawing moment coefficient, C_{M_ψ}, was calculated using the dimensions of the model given in Fig. 2. The moment arm, L, was 1.71 ft. and the flap area, A, was 0.0104 sq. ft. for both the analytic and the experimental investigation.

MATERIALS AND TEST PROCEDURE

THE HYDROFLAPS

The hydroflaps were cut out from 0.031 in. thick brass sheeting to the dimensions shown in Fig. 3. The flaps were bent at the hinge line to get the desired values of α, these angles being checked using templates. The area and the aspect ratio was held constant to eliminate these items as parameters.

THE MODEL

The hull was an 1/8 scale model of a design study for an amphibian and features a high length beam ratio typical of present design trends for flying boats. The dimensions are given in Fig. 2 which was taken from a report by Hugli and Axt (8). The full-scale airplane is small in comparison to the seaplanes that usually need such devices as hydroflaps to aid steering. Since the results of the tests are presented in the form of non-dimensional coefficients the size of the airplane is not important.

The hydroflaps were attached to each side of the afterbody bottom in the positions shown in Figs. 1 and 2. The point O in Figs. 1 and 2, intersection of the hinge line with the afterbody keel, was held at 1.71 ft. aft of the center of gravity in all the tests.

MODEL PARTICULARS

Item	Full Scale*	Model
Scale	1	1/8
Gross weight	2900	--
σ, deg.	--	8
Beam, in.	42	5.25
Step height, in.	4	0.5
Deadrise (step and afterbody)	20°	20°
Length of forebody, in.	156	19.5
Length of afterbody, in.	216	27
Length beam ratio	--	8.85
Wing area, sq.ft.	272	
Horsepower	185	
C_L (Take-off)	1.2	

Stevens Model No. 1055-01 with No. 1043 forebody.

THE TOW TANK

The tests were run in Tank 1 at the Experimental Towing Tank, Stevens Institute of Technology, Hoboken, New Jersey. The tank is the straight rail type and is 109 ft. long, 9 ft. wide, 4.5 ft. deep and of semi-circular cross section. It is filled with fresh water which is held at a temperature of about 69° F. by use of heaters.

---

* See section titled The Model

APPARATUS

The model was mounted in the standard seaplane yawing apparatus of the Experimental Towing Tank described by Libbey (1) and Locke (9). Pin bearings supported the model at the center of gravity which is 1.5 in. forward of the step and 6.5 in. above the forebody keel. The model was given freedom of pitch and heave but was restrained from moving sideways. The heel, ϕ, was set at zero using a spirit level and locked at that position for all tests.

The hull was free to yaw except for the restraint of a calibrated spring. Yawing moments were determined by entering the spring calibration curve with the difference between the preset yaw angle and the running yaw angle. The spring calibration was rechecked each day.

A limitation of the yawing apparatus is that it is very difficult to obtain a moment curve near a discontinuity such as hooking. The angles of yaw were therefore held small to avoid this condition. It is also not possible to determine values on a curve if the slope of that curve is greater than the slope of the spring calibration curve.

In the tests another limitation appeared. It was not possible to read the angle of yaw to any greater accuracy than 0.1° and this gave rise to possible errors of appreciable magnitude in the moments. When weaker yawing springs were installed the model oscillated in yaw and would have required

excessive damping so they could not be used. Although greater accuracy would have been desirable the tests were conducted under this limitation. Further modification of the apparatus could not be made since it was only on loan for these tests.

Figures 4 and 28 show the apparatus and model used in the tests.

PROCEDURE

Tests were run for three different velocities, the speed coefficients, C_V, being 1.06, 1.54 and 2.02. The loadings for these speeds were determined by using the theoretical parabolic unloading curve (2) as shown by the sample calculation given below.

(A) Take-off velocity

$$(V_o)_{f\ s} = (2W/\rho_a A C_L)^{\frac{1}{2}} = 86.5 \text{ ft./sec.}$$

$$(V_o)_m = 86.5\ \lambda^{\frac{1}{2}} = 30.6 \text{ ft./sec.}$$

(B) Gross weight

$$(\Delta_o)_{f\ s} = 2900 \text{ lbs.}$$

$$(\Delta_o)_m = 2900\ \lambda^3 = 5.66 \text{ lbs.}$$

(C) Unloading curve

$$\Delta = \Delta_o\ [1 - (V/V_o)^2\ ] \ .$$

For each velocity the loading was held constant thereby eliminating this item as a parameter.

At each given velocity the trim and the yawing moments were measured for preset hinge angles and angles of opening of the port flap for a variation in angle of yaw of approximately 4° port to 4° starboard.

The angles of opening of the flap, α, which were tested were 0°, 30°, 60° and 90°. Hinge angles, θ, were 21°, 34° 47° and 59°. Hull yawing characteristics were determined without the flaps being installed for use as a basic reference. The flaps were attached to the hull without benefit of recessing the hinge or cutting a groove into which they could retract when closed so it was necessary to run a series of tests for $\alpha = 0$.*

A flap was installed on each side but for the yawing tests only the port flap was opened. Angle of yaw, ψ, was measured as the angle between the direction of motion and the keel line in the horizontal plane. Trim, τ, was measured in the vertical plane as the angle the flat portion of the forebody keel, just ahead of the step, made with the horizontal plane.

---

* The flaps were parallel to the bottom when closed but protruded into the stream a distance equal to the thickness of the flap There was no noticeable effect on the yaw due to this method of installing the flaps.

RESULTS

Figures 9 through 12 are plots of the data obtained by tank tests. All the yawing moments are for opening of the port hydroflap, yaw to port being considered negative.

Figures 13 through 18 are cross plots of the data obtained by tank tests for yaw, ψ, of zero degrees. These graphs show the effect of variation of the parameters C_V, α and θ. It was not possible to vary the deadrise, β, since there was only one model available.

The yawing moment coefficients plotted in Figs. 9 through 18 were computed using the dimensions of the model. No attempt was made to expand to full scale since this is not a part of the study and all coefficients are given in the non-dimensional form

The optimum value of the hinge angle, θ, was found to be in the range of 30° to 40° The theory indicated an average value of 50° would give the highest moments but this magnitude was not reached in the tests due to a sharp break in the moment curves after θ exceeds 40°. The theory did not predict this drop since the dynamic pressure was assumed to vary linearly with Ω, the angle between the flap and the flow, throughout the range considered.

The theoretical study shows the optimum value of the angle of opening of the hydroflap, α, to be in the region of 75°.

Experimental data (Figs. 16, 17, and 18) show a curve with two inflections similar to those that can be made by cross plotting the theoretical data in Fig. 6.

Since there were only four values of α tested (0, 30, 60, 90) the curves in Figs. 16, 17 and 18 do not clearly define the optimum value of α. There is, however, good indication that the greatest yawing moments can be obtained without opening the flap all the way to 90°.

The plots of the experimental data readily show that the yawing moments increase as the velocity is increased for values of the hinge angle less than 50°.

Figures 19, 20 and 21 are a comparison of the results obtained by the analysis and by experiment. The theoretical moments were calculated by using the magnitudes of $\frac{1}{2}\rho V^2 AL$ used in the tests. Values of the constant k in the equation for the yawing moment were determined by calculating the ratio of the values of M_{ψ} as given by analysis and by experiment for corresponding conditions along lines of constant θ. Thus k is the number by which the yawing moment obtained by the equation must be multiplied in order to get it to compare in magnitude with the experimental results. The results are plotted in Fig. 22.

The experimental results indicate a variation in k for variation in speed coefficient, hinge angle, and angle of opening. For the purpose of plotting Fig. 23 an average value of k was assumed for each speed coefficient.

DISCUSSION

The yawing moment equation has rendered results which compare very favorably with the experimental data taken in the towing tank. This indicates that the assumptions used in the development of the equation are reasonable.

One noticeable difference between experiment and the analytics is the magnitude of the moments produced. This difference is to be expected since the equation was developed by considering only the forces on the flap, neglecting the pressures of the water on the hull. In this sense the factor k is a combination of the normal force coefficient on the flap, and the correction factor accounting for the additional forces of water pressure on the hull.

The forces not considered in the derivation of the equation are mainly due to the piling up of water ahead of the open flap. The extent of this piling up of the water varies with the speed coefficient and Ω which is the angle between the surface of the flap and the flow. Since k accounts for these forces in the yawing moment equation it likewise becomes a variable as shown in Fig. 22 (Ω is a function of θ and α).

Figs. 19 through 22 show that for the range tested k varied between 1 and 3. For the purpose of simplification k was assumed to vary only with the speed coefficient. Thus from Fig. 22 an average value of k was determined for each

speed coefficient and these values were plotted in Fig. 23.

Figure 23 indicates that over the range tested the mean value of k approaches 2. Thus consideration of only the forces on the flap accounts for approximately one half of the moment produced. This has an interesting parallel in aerodynamics where the addition of a fin ahead of a movable control surface about doubles the effect of the surface on the static yawing stability (10).

The hull is unstable when operating without hydroflaps as shown by the $\alpha = 0$ curves on Fig. 9. The experimental data indicates that for most of the conditions tested opening of the hydroflaps tends to slightly increase stability. Some of the curves are almost horizontal indicating neutral stability. Generally the effect of varying α over a range of finite values is to translate the curves with little change in the stability characteristics.

It is of interest to note that it is not necessary to open the flaps all the way to 90° to produce maximum yawing moments. The theory indicated that an α of about 75° would give the maximum moment and the data recorded in Figs. 16, 17 and 18 agree with these results within the limits of experimental error. Over the range of α from about 70° to 90° the change in magnitude of the yawing moments is slight showing there is little to gain by operating over this entire region. This is important since it indicates that on actual seaplanes

the mechanisms can be simplifed. How this might compromise the braking action produced by the hydroflaps is covered by Feuerbach (6).

Figures 6, 7 and 8 are plots of the data obtained from the yawing moment equation for a variation in deadrise. It is interesting to note that increasing the deadrise had little effect on the maximum moment that can be produced.

Although the study is in general fairly well substantiated by experiment it is felt that the effect of variation of deadrise has not been fully determined. The forces of water pressure on the hull are of considerable magnitude and an increase in deadrise might amplify this condition. There was only one model available for these tests so further investigation of this parameter was not attempted.

In Figs. 13, 14 and 15 the curves obtained by test show that a rapid drop in dynamic pressure occurs after the hinge angle, θ, exceeds a value of 35° to 40°.

The photographs in Figs. 25 and 26 were taken in an effort to account for this phenomena. Figures 25 and 26 are for identical conditions except that in Fig. 25 θ was equal to 34° and in Fig. 26 θ equals 47°. The only difference that can be noted is that the spray from the flap is a little higher and has moved forward slightly in the case of the higher hinge angle. The location of the flap can be seen in Fig. 27.

Unfortunately the photographs are insufficient to yield an answer. The difference in the spray is not enough to predict such a large change in the moment. The trim did not change but this hull is fairly "stiff" and thus requires high pitching moments to change the trim so no conclusions can be drawn as to any variation of forces in that plane.

It is apparent that in order to conclusively explain this phenomena underwater photographs of the flow pattern are needed, along with measurements of the draft on each side of the hull. It would also be advantageous to measure the forces on the flap and study alone their variation with a variation in speed coefficient and the geometric parameters. Provisions for such tests were not immediately available and so they were not attempted.

We cannot do more than say here that the hinge angle has a critical value beyond which the forces produced rapidly drop below the predicted values. Thus the flap undergoes a phenomena which may well be referred to as a stall.

Figure 27 is the condition for both flaps open and clearly shows an air space under the sternpost resulting from the deflection of the flow away from the hull by the flaps. This condition was readily observed at the higher velocities for either one or both flaps open, there being no water on the back side of the open flap. At the lower velocities where the deflection of the water was not so extensive this condition could

not be easily seen. However, in looking down through the water it was possible to see what appeared to be a surface of discontinuity trailing aft from the edge of the flap. This suggests that an air space behind the flap also existed at the lowest speed tested. Feuerbach (6) found that this condition has a marked effect on the trim.

A comparison was made between the effectiveness of hydroflaps and a fully submerged water rudder. For similar conditions of aspect ratio, velocity and dimensions of the model it was found that the flap requires approximately 6/10 the area of the rudder to produce equal yawing moments. This is readily explained by the fact that in case of a hydroflap the water pressure acts both on the flap itself and on the adjacent parts of the hull, while the rudder (1) was of the "spade" type, and had no fixed surface in front of it.

CONCLUSIONS

The equation for the yawing moment derived in the analysis is:

$$M_\psi = k \tfrac{1}{2} \rho V^2 AL \ \sin\theta \sin\alpha \left[\cos\theta \sin\alpha \cos\beta + \cos\alpha \sin\beta\right].$$

In the derivation the side forces of the water upon the hull were not considered so k became not only a normal force coefficient but a corrective factor. For the hull tested the theoretical results rendered by the equation fell below the experimental values and k was found to be approximately 2. This value of k brings the experimental and the theoretical results into close agreement indicating that the equation gives good results within the limits of the assumptions upon which it is based.

Under comparative conditions the hydroflaps have been found to require about 6/10 the area of a fully submerged water rudder. The hydroflap actually tested had 50 per cent larger area than the usual water rudder, and the total yawing moment, therefore, was $2\frac{1}{2}$ times larger.

Maximum yawing moments are obtained for a hinge angle of 30° to 40°. Beyond this maximum there is a critical value where the moments drop off rapidly. The reason for this phenomena has not been determined.

Tests were only made for one value of deadrise so the effect of variation of this parameter has not been fully established. Side forces of the fluid on the hull are of consider-

able magnitude and an increase in deadrise might amplify this condition.

There is very little variation in the yawing moments when the angle of opening of the hydroflaps is varied over the range of 70° to 90°. Insofar as yawing is concerned the hydroflaps can be designed to open only to 70° without appreciably compromising their function.

Increases in the speed coefficient results in higher moments since the dynamic pressure is increased. Changes in the speed coefficient had a marked effect on the slopes of the moment curves but did not otherwise alter their general shape.

BIBLIOGRAPHY

1. Libbey, L.B. The Effectiveness of Water Rudders on Flying Boats. Thesis S.I.T., Hoboken, N.J., 1950.

2. Korvin-Kroukovsky, B.V. Hydrodynamic Design of Seaplanes. Unedited Class Notes (FD 215) S.I.T., Hoboken, N.J. 1950.

3. Pierson, J.D. Directional Stability of Flying Boat Hulls During Taxiing. Journal of Aeronautical Sciences, Vol. 11, p. 3, 1944.

4. Locke, F.W.S., Jr. A Preliminary Correlation of the Behavior of Water Rudders on Seaplanes and Flying Boats. NACA T.N. 1387, 1947.

5. Parkinson, J.B. Appreciation and Determination of the Hydrodynamic Qualities of Seaplanes. NACA T.N. 1290, 1947.

6. Feuerbach, T. Effect of Hydroflaps on Pitching and Braking of Flying Boats. Thesis S.I.T., Hoboken, N.J., 1951.

7. Smith, Gale, and Neelley. New Analytic Geometry. Ginn and Company, New York, 1928.

8. Hugli, W.C. and Axt, W.C. Hydrodynamic Investigation of a Series of Hull Models Suitable for Small Flying Boats and Amphibians. Report No. 388, Experimental Towing Tank, S.I.T., Hoboken, N.J., 1949.

9. Locke, F.W.S. Jr. Some Yawing Tests of a 1/30-Scale Model of the Hull of the XPB2M-1 Flying Boat. NACA Wartime Report W-66, July 1943.

10. Durand, W.F. Aerodynamic Theory. Vol. V, Durand Reprinting Committee, C.I.T., Pasadena, California, 1943.

11. Benson and Bidwell. Bibliography and Review of Information Relating to the Hydrodynamics of Seaplanes. NACA Wartime Report No. L-230, 1945.

12. Larsen, K.D. Review of Previously Published Rudder Studies. E.T.T., S.I.T., NACA TM No. 79, 1946.

TABLE Ia

TRIM AND YAW DATA UNDER STATIC CONDITIONS

C_v	C_Δ	[illegible] in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
			Bare Hull				
1.06	1.08	0.7	0	0	3.1	0	0
		0.7	1.1 s	0.5	3.1		
		1.5	2.1 s	0.5	3.0		
		1.5	3.3 s	1.5	3.0		
		0.7	4.4 s	2.0	3.1		
		0.7	2.85 s	1.3	3.1		
		0.7	1.7 s	1.0	3.1		
		0.7	0.55 s	0.3	3.1		
		0.7	1.1 p	0.5	3.1		
		1.5	3.4 p	2.0	3.0		
		0.7	2.2 p	1.0	3.1		
		-	1.7 p	1.0	-		
1.54	1.04	0	0	0	5.5		
		0	1.1 s	0.5	5.5		
		0	2.4 s	2.0	5.6		
		0	3.5 s	2.5	-		
		0	4.6 s	3.0	5.6		
		0	1.9 s	2.0	5.6		
		0	1.2 p	1.0	5.6		
		0	2.3 p	1.3	5.6		

TABLE Ib

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
			Hull with Flaps On				
2.02	0.99	3.5	2.5 p	2.5	6.2	0	0
		2.0	1.2 p	1.0	6.1		
		0.5	0	0	6.0		
		1.5	1.2 s	1.0	6.1		
		1.5	2.5 s	2.5	6.2		
		2.5	3.9 s	4.5	6.3		
		-	5.0 s	5.0	6.7		
		2.0	0	0	5.8		
		-	1.2 s	0.8	-		
		2.0	2.5 s	2.5	6.1		
		-	1.2 p	1.0	-		
[illegible]	1.04	1.5	1.2 p	1.0	5.3		
		1.5	0	0	5.3		
		0.5	1.1 s	0.5	5.4		
		0.5	2.5 s	2.5	5.4		
[illegible]	1.08	1.5	2.2 s	1.0	3.0		
		-	1.1 s	2.5	-		
		1.5	0	0	3.0		
		1.5	1.1 p	0.5	3.0		

TABLE Ic

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
			Hull with Flaps On; $\theta = 23^\circ$				
1.06	1.08	1.5	1.3 p	1.5	3.0	60	0
		1.5	2.5 p	2.5	3.0	60	
		1.5	0.1 p	0.5	3.0	30	0
		1.5	2.5 p	2.3	3.0		
		0.7	1.0 s	0	3.1		
		0.7	3.1 s	0.5	3.1		
		0.7	5.3 s	1.5	3.1		
		0.7	2.1 s	0.5	3.1		
1.54	1.04	- 1.5	2.0 s	0	5.7		
		- 1.5	4.1 s	0.5	5.7		
		0	0.5 p	2.5	5.6		
		0	1.6 p	3.0	5.6		
		0.5	2.8 p	4.0	5.5		
2.02	0.99	3.0	3.0 p	5.0	6.3		
		1.5	1.9 p	4.5	6.2		
		0.5	0.7 p	3.5	6.2		
		0.5	0.5 s	2.5	6.1		
		1.0	1.4 s	2.0	6.1		
		- 0.5	3.9 s	0.5	6.7		
		0	0	0	6.1	30	30
		1.5	3.0 s	0	6.2		
		2.5	3.0 p	0	6.2		

TABLE Id

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
		Hull with Flaps On; $\theta = 23^\circ$					
1.54	1.04	0.7	0	0	5.4	30	30
		0.5	3.0 s		5.5		
		0.5	3.0 p		5.5		
1.06	1.08	1.5	3.0 p		3.0		
		1.5	0		3.0		
		1.5	3.0 s		3.0		
		1.5	0		3.0	60	60
		1.5	3.0 p		3.0		
		1.5	3.0 s		3.0		
1.54	1.04	0	3.0 p		5.6		
		0	0		5.6		
		- 1.5	3.0 s		5.7		
2.02	0.99	1.5	3.0 s		6.2		
		0	0		6.1		
		2.5	3.0 p		6.2		
		-10.0	3.0 s		7.3	90	90
		-10.5	0		7.4		
		- 9.5	3.0 p		7.8		
1.54	1.04	- 4.0	3.0 p		6.0		
		- 4.0	0		6.0		
		- 4.0	3.0 s		6.0		

TABLE Ie

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	γ deg.	α_p deg.	α_s deg.
			Hull with Flaps On; $\theta = 23^\circ$				
1.06	1.08	0.7	0	0	3.1	90	90
		0.7	3.0 s		3.1		
		0.7	3.0 p		3.1		
2.02	0.99	0.5	1.5 p	7.5	6.3	90	0
		0	3.0 p	10.0	6.8		
		- 1.5	0.7 p	8.5	6.5		
		- 3.0	0.2 s	9.0	6.5		
		3.0	5.0 s	0	6.4		
		-	2.5 p	10.0	-		
			1.3 p	9.0	-		
1.54	1.04	0	1.2 p	6.0	5.6		
		- 2.5	2.3 p	6.7	5.8		
		- 1.5	0.1 p	5.5	5.7		
		- 2.5	2.0 s	4.5	5.8		
		- 2.5	4.1 s	4.5	5.8		
1.06	1.08	1.5	5.0 s	0	3.0		
		1.5	2.7 s	1.5	3.0		
		1.5	0.5 s	2.5	3.0		
		1.5	0.6 p	3.0	3.0		
		1.5	1.5 p	2.5	3.0		
		1.5	2.6 p	3.0	3.0		

TABLE If

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
		Hull with Flaps On; $\theta = 23^\circ$					
2.02	0.99	0	1.0 p	5.0	6.3	60	0
		1.5	3.6 p	8.0	6.6		
		- 2.0	0.5 p	6.7	6.5		
		- 3.0	1.0 s	5.0	6.6		
		- 4.0	1.9 s	5.5	6.7		
		- 4.0	3.0 s	5.0	6.9		
1.54	1.04	- 1.5	3.0 p	5.0	5.7		
		- 1.5	1.9 p	4.5	5.7		
		- 2.5	0.8 p	4.0	5.8		
		- 3.5	0.4 s	3.0	5.9		
		- 3.5	1.4 s	3.0	5.9		
		- 3.5	3.5 s	2.5	5.9		
1.06	1.08	0.7	4.0 s	0	3.1		
		0.7	1.9 s	0.5	3.1		
		0.7	0.8 s	1.0	3.1		
		1.5	0.4 p	2.0	3.0		
		Hull with Flaps On; $\theta = 47^\circ$					
2.02	0.99	9.5	1.5 p	7.5	5.3	90	0
		8.0	2.7 p	8.5	5.7		
		9.5	4.0 p	10.0	5.9		
		8.0	0.5 p	7.5	5.2		

TABLE Ig

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
			Hull with Flaps On; $\theta = 47^\circ$				
2.02	0.99	9.5	1.8 s	6.0	5.1	90	0
		9.5	4.0 s	4.5	5.5		
1.54	1.04	4.0	4.8 s	1.0	5.0		
		3.0	3.5 s	2.5	5.1		
		2.5	1.3 s	3.5	5.2		
		2.5	0.9 p	4.5	5.2		
		-	2.1 p	5.4	-		
		3.0	3.1 p	5.4	5.1		
1.06	1.08	2.8	2.7 p	3.5	2.8		
		2.8	1.5 p	2.5	2.8		
		2.8	0.5 p	2.5	2.8		
		2.2	1.8 s	1.0	2.9		
		-	0.6 s	2.0	-		
		1.5	3.9 s	0.5	3.0		
		2.8	0.5 p	2.5	2.8	60	0
		2.2	1.6 p	3.0	2.9		
		2.2	2.7 p	3.5	2.9		
		2.2	1.8 s	1.0	2.9		
		2.2	4.0 s	0	2.9		
1.54	1.04	4.0	3.8 s	1.0	5.0		
		4.0	1.5 s	2.5	5.0		

TABLE Ih

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
			Hull with Flaps On; $\theta = 47^\circ$				
1.54	1.04	3.0	0.8 p	4.0	5.1	60	0
		4.0	1.9 p	4.5	5.0		
		4.0	3.0 p	5.0	5.0		
2.02	0.99	8.0	3.7 p	8.5	5.8		
		7.0	2.3 p	6.5	5.7		
		7.0	1.1 p	5.4	5.5		
		8.2	1.1 s	4.5	5.2		
		9.0	3.1 s	4.5	5.2		
		3.5	0.6 p	3.0	5.8	30	0
		4.5	1.9 p	4.5	5.8		
		5.5	2.9 p	4.5	5.9		
		3.0	1.6 s	2.0	5.9		
		5.5	4.1 s	0	6.0		
1.54	1.04	0	4.3 s	1.0	5.5		
		-1.0	1.9 s	0.5	5.6		
		0	0.8 p	4.0	5.5		
		0.7	1.8 p	4.0	5.4		
		-1.0	2.8 p	4.0	5.6		
1.06	1.08	1.5	2.4 p	2.0	3.0		
		1.5	1.1 p	0.5	3.0		
		1.5	0.2 p	1.0	3.0		

TABLE Ii

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg
			Hull with Flaps On; $\theta = 47^\circ$				
1.06	1.08	1.0	2.0 s	0	3.1	30	0
		1.0	4.1 s	0.5	3.1		
		1.0	0		3.1	30	30
		1.5	3.0 p		3.0		
		1.0	3.0 s		3.0		
1.54	1.04	0.7	3.0 s		5.4		
		1.5	0		5.3		
		2.3	3.0 p		5.2		
2.02	0.99	8.0	3.0 p		5.8		
		5.0	0		5.5		
		6.0	3.0 s		5.8		
		10.5	0		4.8		
		11.5	3.0 s		5.0		
		13.5	3.0 p		5.0		
1.54	1.04	4.0	0		5.0		
		5.5	3.0 p		4.8		
		4.7	3.0 s		4.9		
1.06	1.08	3.5	3.0 s		2.7		
		4.7	0		2.5		
		3.5	3.0 p		2.7		
		2.2	0		2.9	90	90

TABLE Ij

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
			Hull with Flaps On; $\theta = 47^\circ$				
1.06	1.08	2.8	3.0 p		2.8	90	90
		2.8	3.0 s		2.8		
1.54	1.04	4.0	3.0 s		5.0		
		3.0	0		5.1		
		4.0	3.0 p		5.0		
2.02	0.99	13.0	3.0 p		5.1		
		12.5	0		4.5		
		11.5	3.0 s		5.1		
			Hull with Flaps On; $\theta = 60^\circ$				
2.02	0.99	2.5	0.6 p	3.0	5.9	30	0
		4.5	1.8 p	4.0	5.9		
		6.0	2.9 p	4.5	6.0		
		5.0	1.8 s	1.0	5.8		
		6.5	4.0 s	0	5.9		
1.54	1.04	2.3	4.1 s	0.5	5.2		
		2.3	1.9 s	0	5.2		
		1.5	0.3 p	1.25	5.3		
		0.7	1.5 p	2.5	5.4		
		0	2.6 p	3.0	5.5		
1.06	1.08	1.5	2.5 p	2.5	3.0		
		1.5	1.3 p	1.5	3.0		

TABLE Ik

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
Hull with Flaps On; $\theta = 60^\circ$							
1.06	1.08	1.5	0.2 p	1.0	3.0	30	0
		1.5	2.0 s	0	3.0		
		1.5	4.1 s	0.5	3.0		
		2.2	0.5 p	2.5	2.9	60	0
		2.0	1.5 p	2.5	2.9		
		2.2	2.6 p	3.0	2.9		
		2.2	0.8 s	1.0	2.9		
		2.8	3.0 s	0	2.8		
1.54	1.04	4.0	2.8 s	1.0	5.0		
		3.0	0.4 s	3.0	5.1		
		2.3	0.8 p	4.0	5.2		
		2.3	1.9 p	4.5	5.2		
		2.3	3.0 p	5.0	5.2		
2.02	0.99	11.0	3.9 p	9.5	5.6		
		8.5	2.5 p	7.5	5.6		
		8.5	1.2 p	6.0	5.3		
		8.0	0	5.0	5.1		
		11.0	2.1 s	4.5	5.0		
		12.5	4.0 s	2.5	5.0		
		9.5	1.5 p	7.5	5.1	90	0
		10.0	2.9 p	9.5	5.5		

TABLE I1

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ eg.	α_p deg.	α_s deg.
Hull with Flaps On; $\theta = 60^\circ$							
2.02	0.99	9.0	4.2 p	11.0	5.9	90	0
		9.0	0.3 p	6.6	5.1		
		9.5	0.8 s	6.0	5.0		
		9.5	4.4 s	3.5	5.5		
		10.0	2.5 s	5.0	5.2		
1.54	1.04	2.3	3.0 s	2.5	5.2		
		1.5	0.1 s	4.5	5.3		
		1.5	0.9 p	4.5	5.3		
		1.5	2.0 p	5.0	5.3		
		1.5	3.1 p	5.5	5.3		
1.06	1.08	1.5	2.5 p	2.5	3.0		
		1.5	1.5 p	2.5	3.0		
		1.5	0.5 p	2.5	3.0		
		1.5	0.8 s	1.0	3.0		
		1.5	3.0 s	0	3.0		
		4.0	0		2.6	90	90
		4.7	3.0 s		2.5		
		4.7	3.0 p		2.5		
1.54	1.04	10.2	3.0 p		4.2		
		9.5	0		4.3		
		10.2	3.0 s		4.2		

TABLE Im

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
		Hull with Flaps On; [illegible] = 60°					
2.02	0.99	17.5	3.0 s	0	4.1	90	90
		17.5	0		3.0		
		19.5	3.0 p		4.1		
		16.5	0		4.0	60	60
		16.5	3.0 s		4.2		
		18.0	3.0 p		4.2		
1.54	1.04	9.5	3.0 p		4.3		
		8.8	0		4.4		
		9.5	3.0 s		4.3		
1.06	1.08	4.7	3.0 s		2.5		
		3.5	0		2.7		
		4.7	3.0 p		2.5		
		2.2	0		2.9	30	30
		1.5	3.0 s		3.0		
		2.2	3.0 p		2.9		
1.54	1.04	3.0	3.0 p		5.1		
		2.3	0		5.2		
		3.0	3.0 s		5.1		
2.02	0.99	9.5	3.0 s		5.4		
		7.5	0		5.2		
		10.5	3.0 p		5.4		

TABLE In

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
			Hull with Flaps On; $\theta = 34^\circ$				
1.06	1.08		0.1 p	0.5		30	0
			2.4 p	2.0			
			1.2 p	1.0			
			0.9 s	0.5			
1.54	1.04		0.5 s	2.5			
			0.7 p	3.5			
			1.75 p	3.75			
2.02	0.99		0.5 p	2.5			
			0.7 s	1.25			
			0.5 p	5.0			
			0.1 p	5.5			
			1.4 p	7.0			
			0.1 p	5.5			
			1.1 s	4.5			
			0.9 p	4.5		60	0
			1.1 p	10.5			
			0.1 p	10.5			
1.54	1.04		0.9 s	5.5			
			0.5 p	7.5			
			1.5 p	7.5			
1.06	1.08		0.5 p	2.5			

TABLE Io

C_V	C_Δ	M in.lb.	ψ deg.	M_ψ in.lb.	τ deg.	α_p deg.	α_s deg.
Hull with Flaps On; $\theta = 60^\circ$							
1.06	1.08		0.5 s	2.5		60	0
			1.6 p	3.0			
			0.6 p	3.0		90	0
			0.5 s	2.5			
			1.8 p	4.0			
1.54	1.04		2.8 p	9.0			
			1.7 p	8.5			
			0.7 p	8.5			
			0.4	8.0			
2.02	0.99		0.2 p	11.0			
			1.6 p	13.0			
			0.6 p	12.0			

TABLE IIa

APPLIED MOMENT VS. TRIM DATA

C_V	C_Δ	M in.lb.	ψ deg.	τ deg.
		Bare Hull		
1.54	1.04	0	3 s	5.6
		7.63	3 s	4.6
		15.3	3 s	3.5
		-22	3 s	8.1
		-11	3 s	6.8
		-11	0	6.8
		-22	0	8.1
		15.3	0	3.5
		15.3	5 p	3.5
		-22	5 p	8.1
1.06	1.08	-22	5 p	6.0
		-11	5 p	4.8
		7.6	5 p	2.0
		15.3	5 p	0.9
		15.3	0	0.9
		-22	0	6.0
		0	0	3.2
		0	5 s	3.1
		-22	5 s	6.0
		15.3	5 s	0.9

TABLE IIb

C_V	C_Δ	M in.lb.	ψ deg.	τ deg.
		Bare Hull		
2.02	0.99	15.3	5 s	4.6
		7.6	5 s	5.8
		-11	5 s	8.1
		-22	5 s	10.1
		0	0	6.1
		-11	0	7.3
		7.6	0	5.3
		15.3	0	4.3
		-22	0	9.1
		0	5 s	6.6
		0	5 p	7.0
		-11	5 p	8.8
		7.6	5 p	6.0
		15.3	5 p	5.0
		-22	5 p	10.2

TABLE III

RESISTANCE DATA

$\psi = 0^{\circ}; \alpha_p = \alpha_s$

α	$C_V = 1.06$		$C_V = 2.02$	
	τ	R	τ	R
deg.	deg.	lb.	deg.	lb.
		$\theta = 47^{\circ}$		
90	2.9	0.465	4.5	1.47
60	2.5	0.415	5.0	1.29
30	3.1	0.38	5.5	1.13
		$\theta = 60^{\circ}$		
30	2.9	0.37	5.2	1.15
60	2.7	0.46	4.0	1.46
90	2.6	0.52	3.8	1.71
		Bare Hull		
	3.0	3.3	5.8	1.08

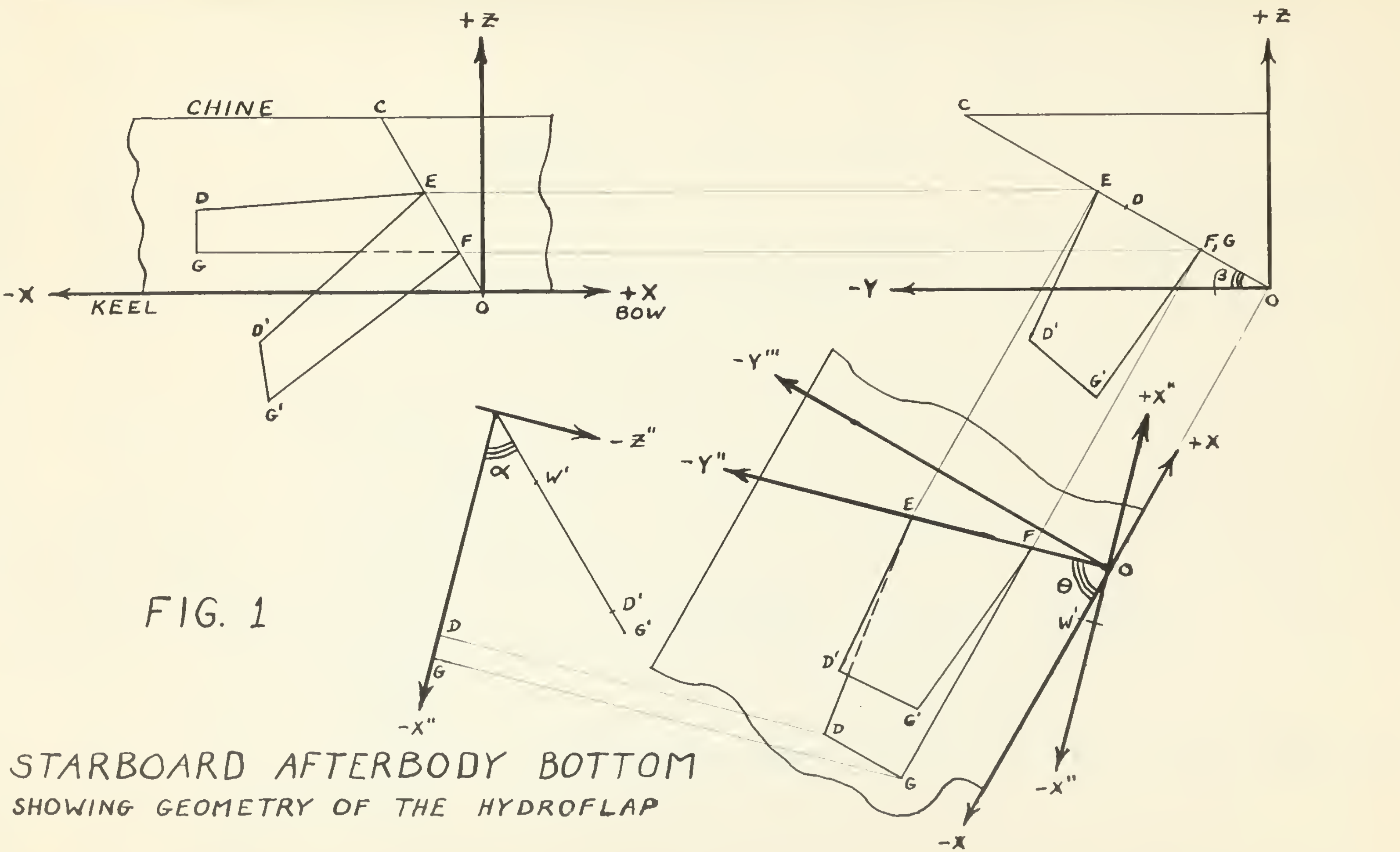


FIG. 1

STARBOARD AFTERBODY BOTTOM
SHOWING GEOMETRY OF THE HYDROFLAP

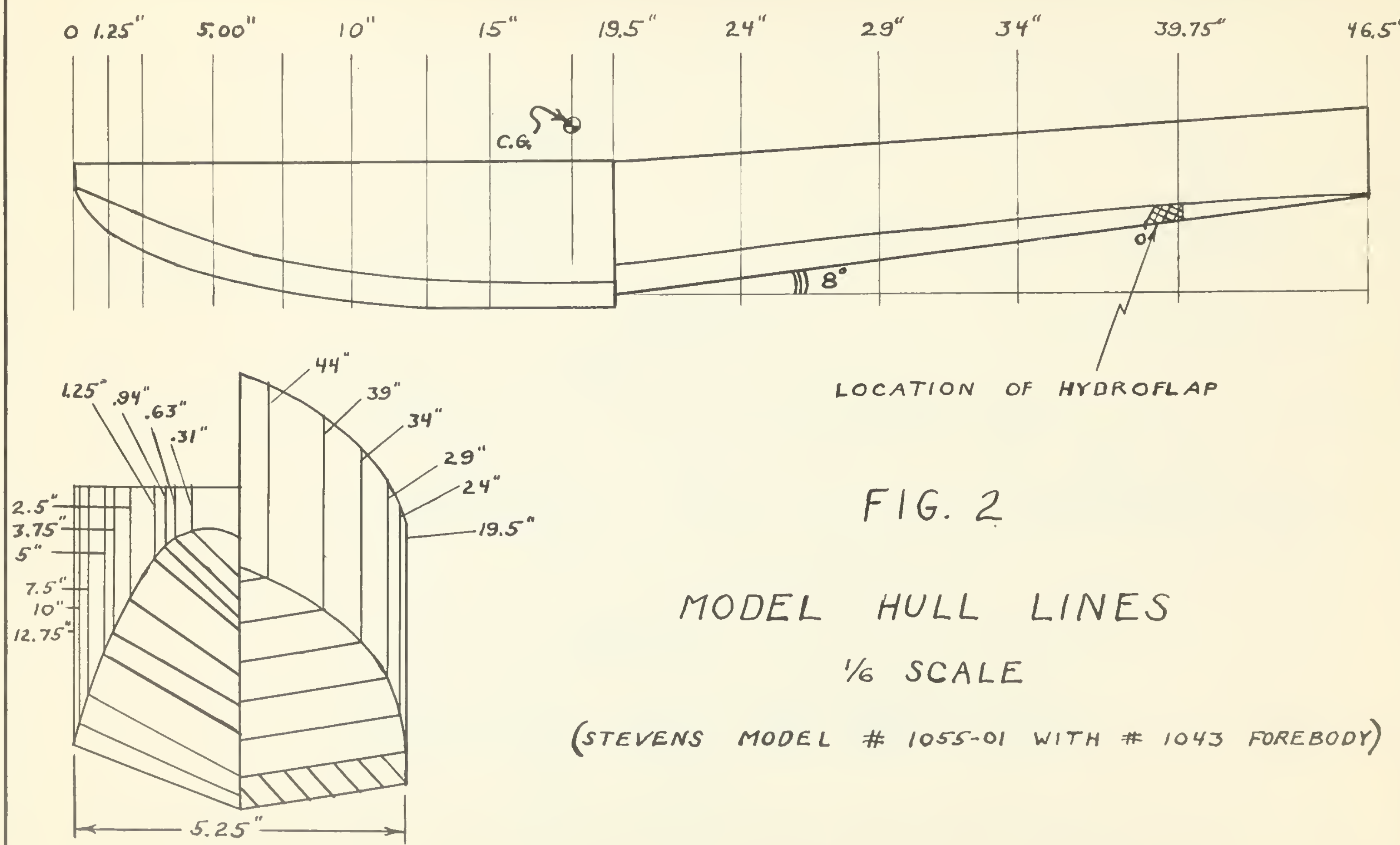


FIG. 2

MODEL HULL LINES

1/6 SCALE

(STEVENS MODEL # 1055-01 WITH # 1043 FOREBODY)

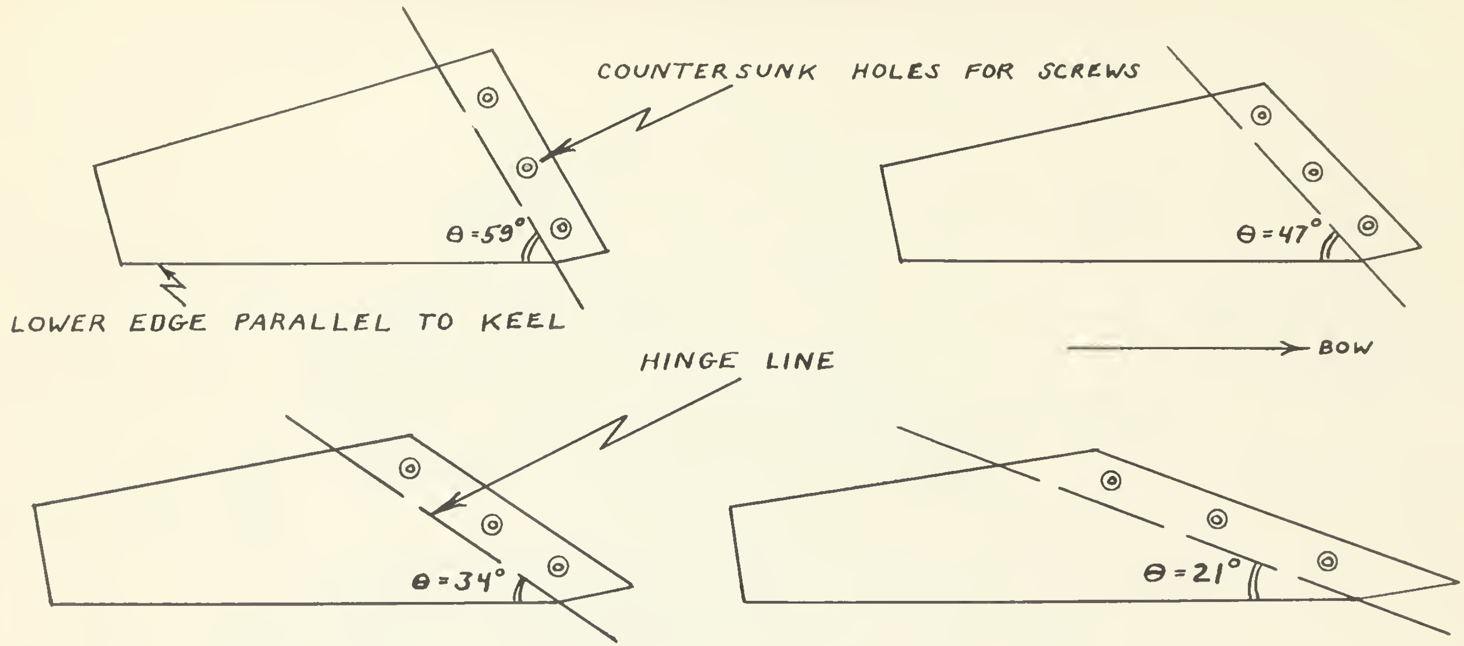
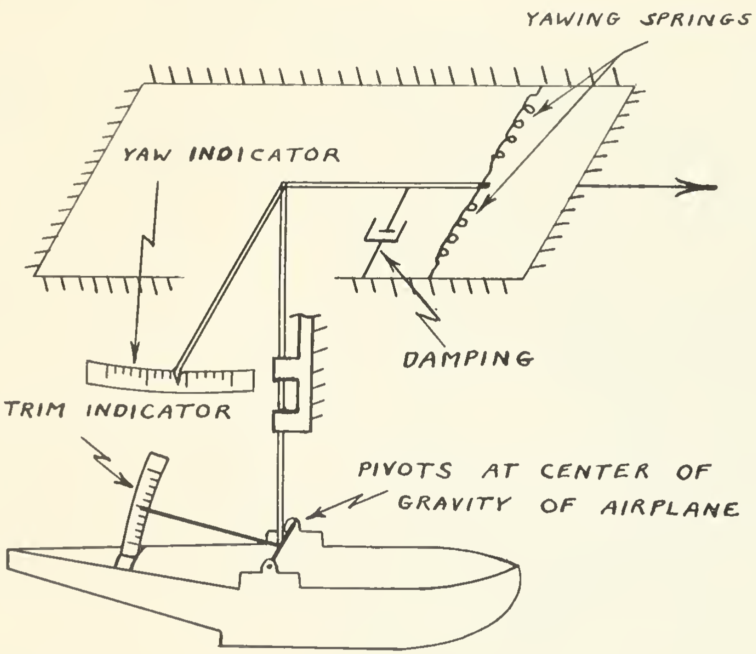


FIG. 3

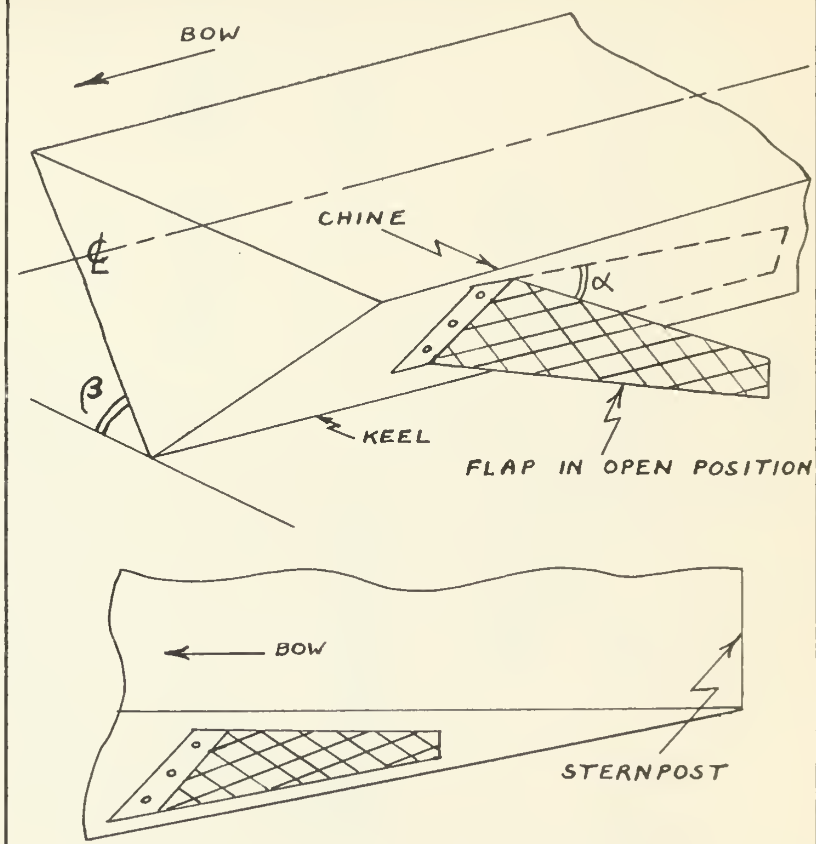
HYDROFLAPS USED IN TANK TESTS

FULL SCALE

FIG. 4



SCHEMATIC OF APPARATUS



ISOMETRIC VIEWS OF HYDROFLAP

FIG. 5

FIG. 6

PLOT OF DATA OBTAINED FROM YAWING MOMENT EQUATION

(FOR MODEL USED IN THE TESTS)

$\beta = 20°$

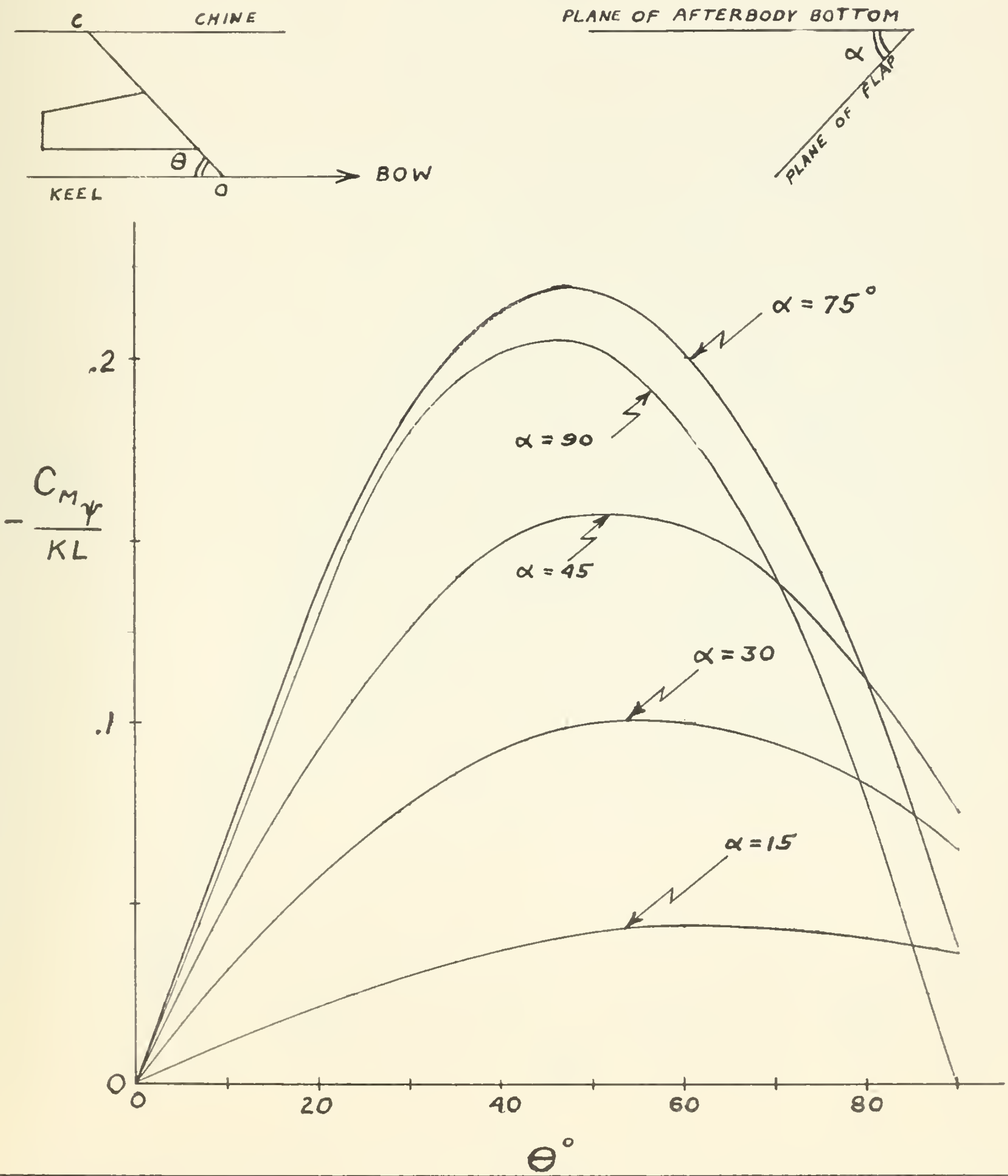


FIG. 7

PLOT OF DATA OBTAINED FROM YAWING MOMENT EQUATION

$\beta = 30°$

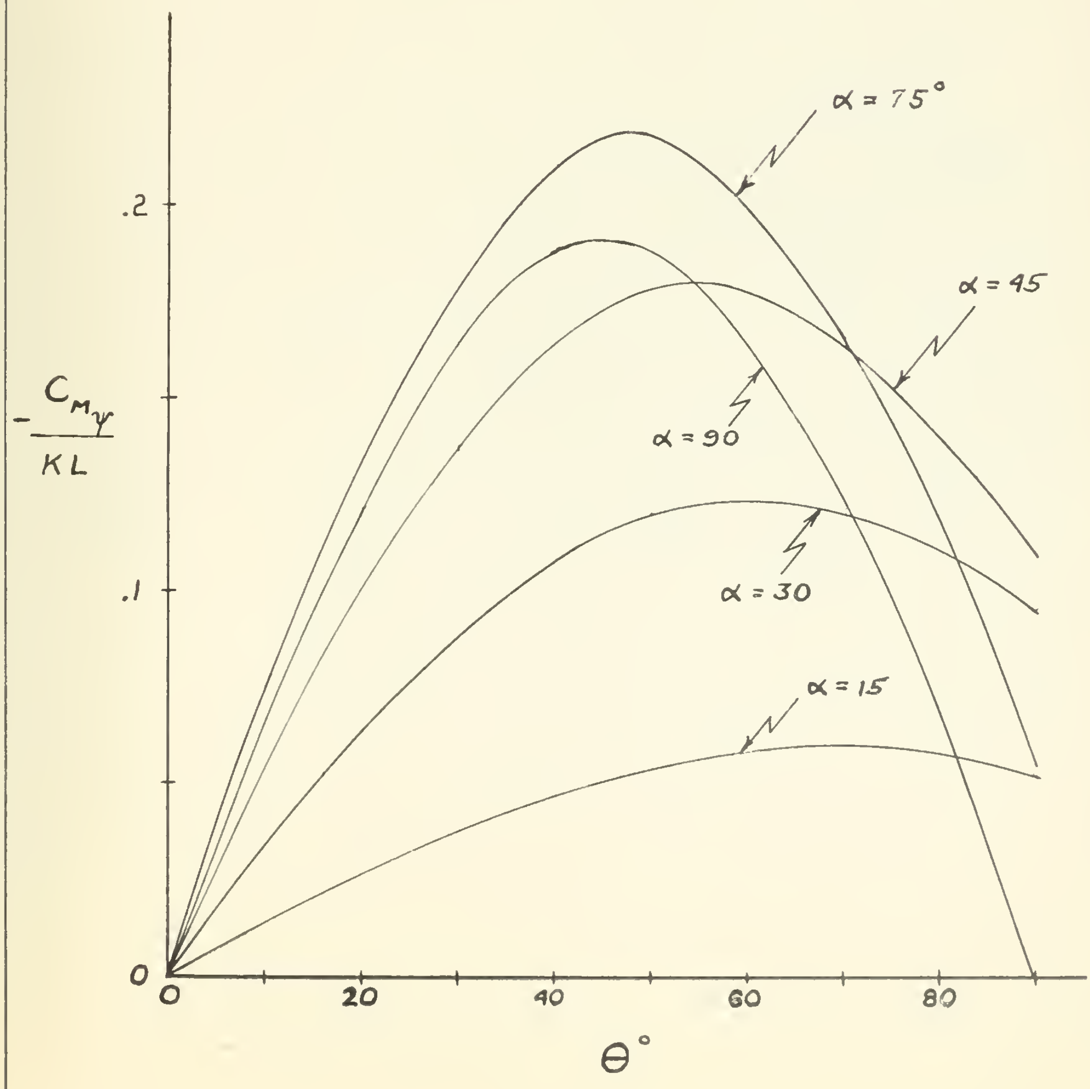


FIG. 8

PLOT OF DATA OBTAINED FROM YAWING MOMENT EQUATION

$\beta = 40°$

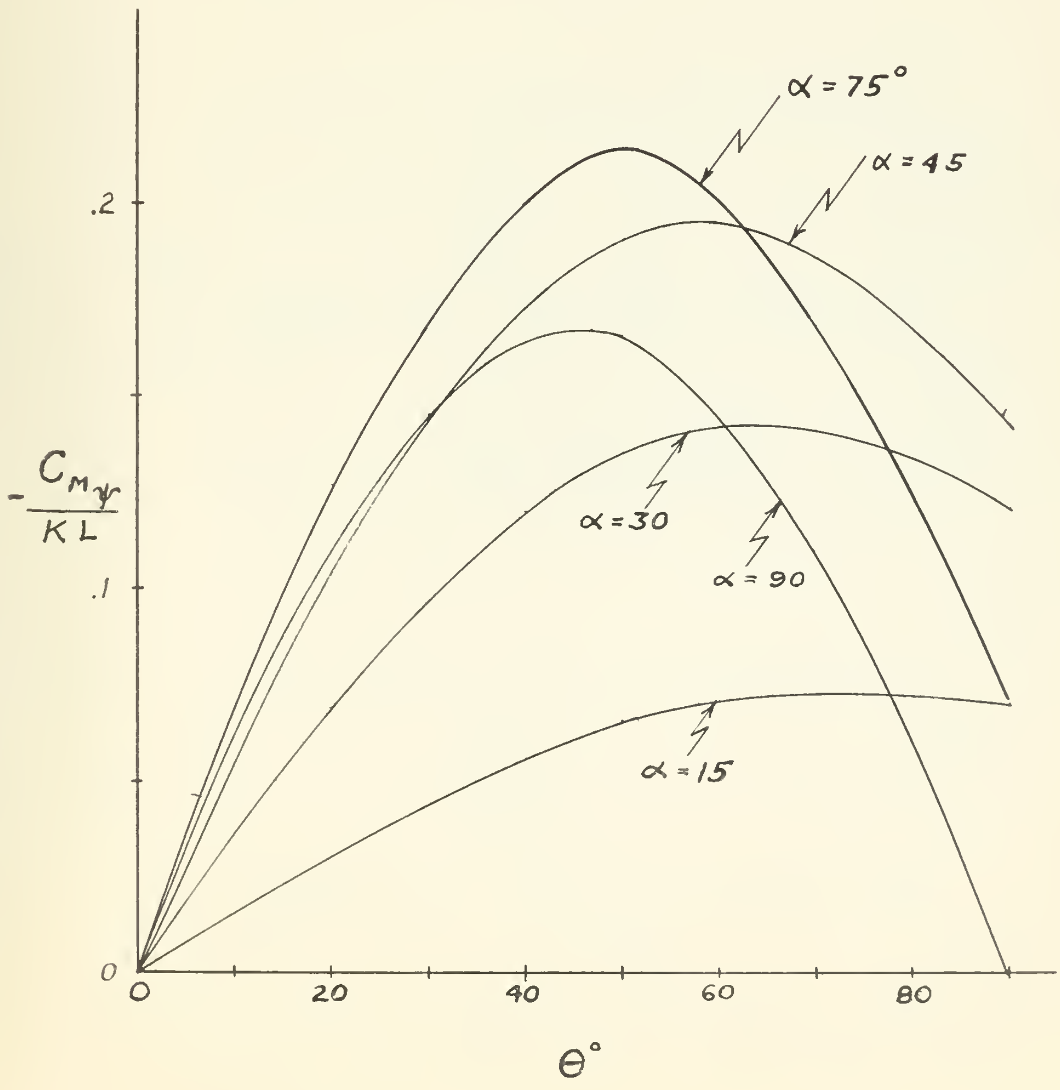
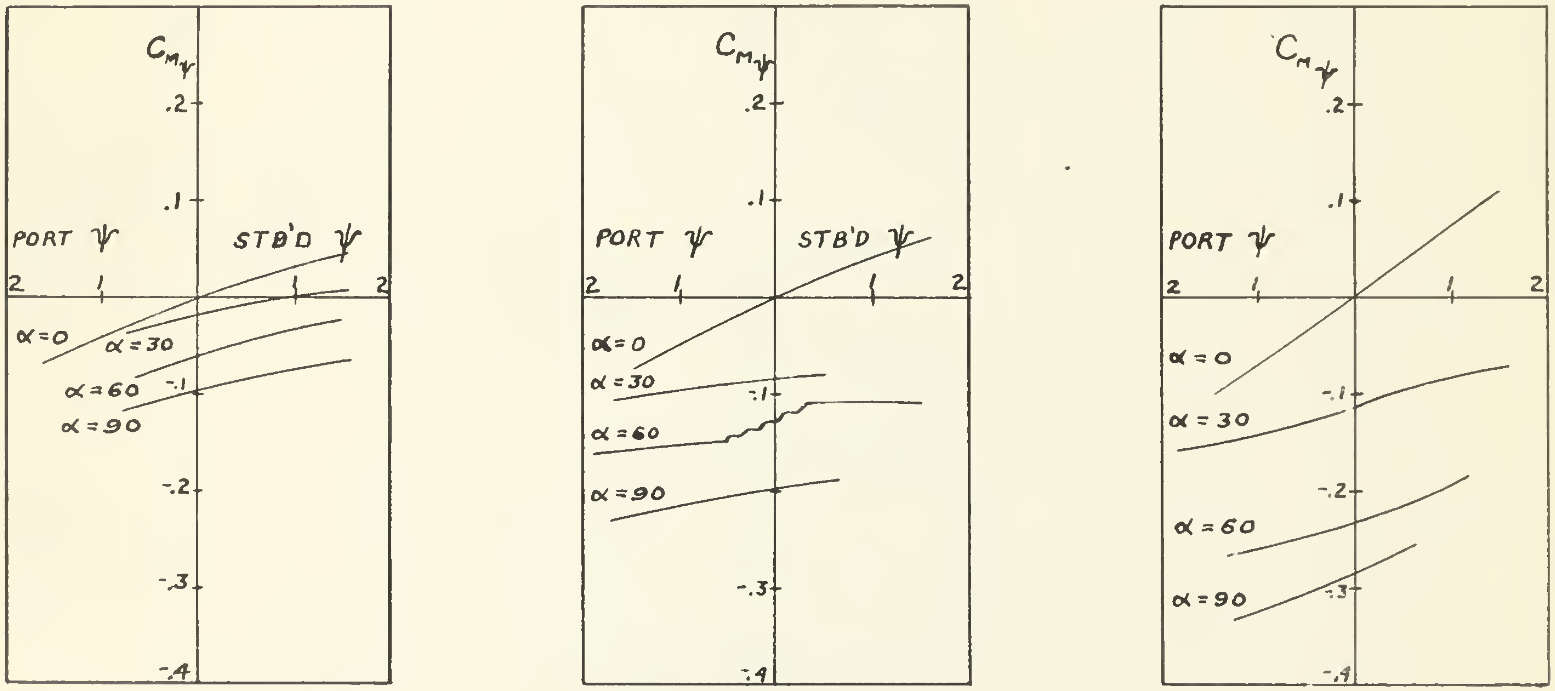


FIG. 9

C_{M_ψ} VS ψ° AS DETERMINED BY EXPERIMENT ON THE MODEL

$\theta = 21^\circ$

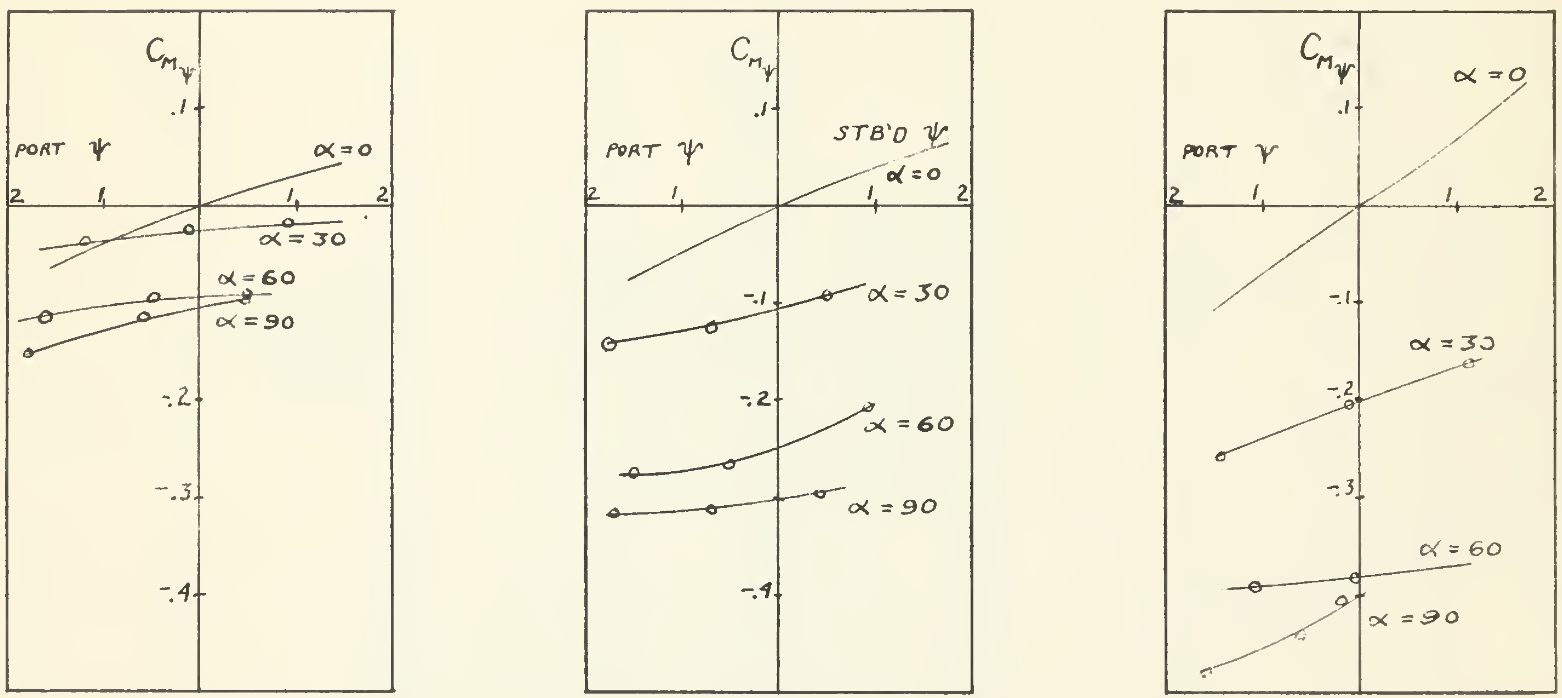


$C_v = 1.06$ $C_\Delta = 1.08$ $C_v = 1.54$ $C_\Delta = 1.04$ $C_v = 2.02$ $C_\Delta = 0.99$

FIG. 10

C_{M_ψ} VS ψ° DETERMINED BY EXPERIMENT

$\theta = 34^\circ$

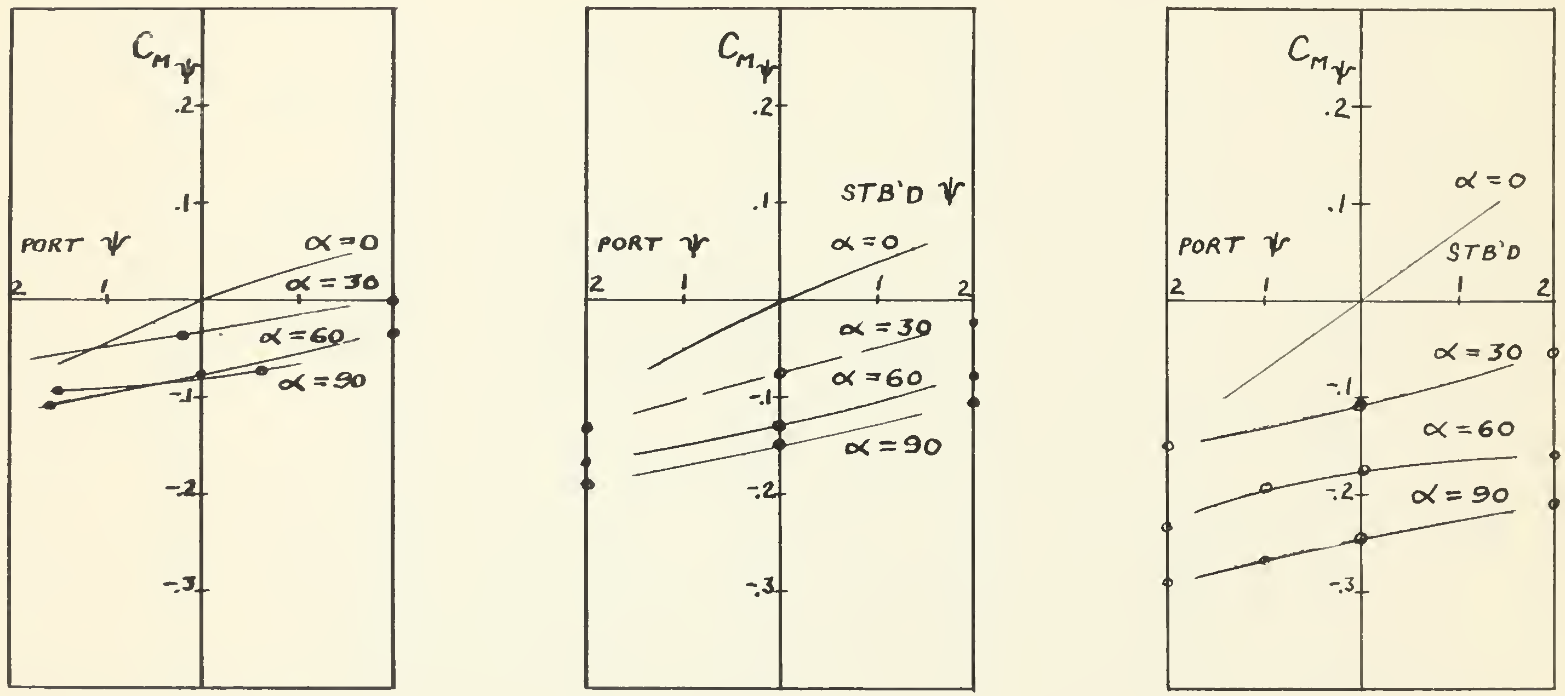


$C_v = 1.06$ $C_\Delta = 1.08$ $C_v = 1.54$ $C_\Delta = 1.04$ $C_v = 2.02$ $C_\Delta = 0.99$

FIG 11

C_{M_ψ} VS ψ DETERMINED BY EXPERIMENT

$\theta = 47^\circ$



$C_v = 1.06$ $C_\Delta = 1.08$

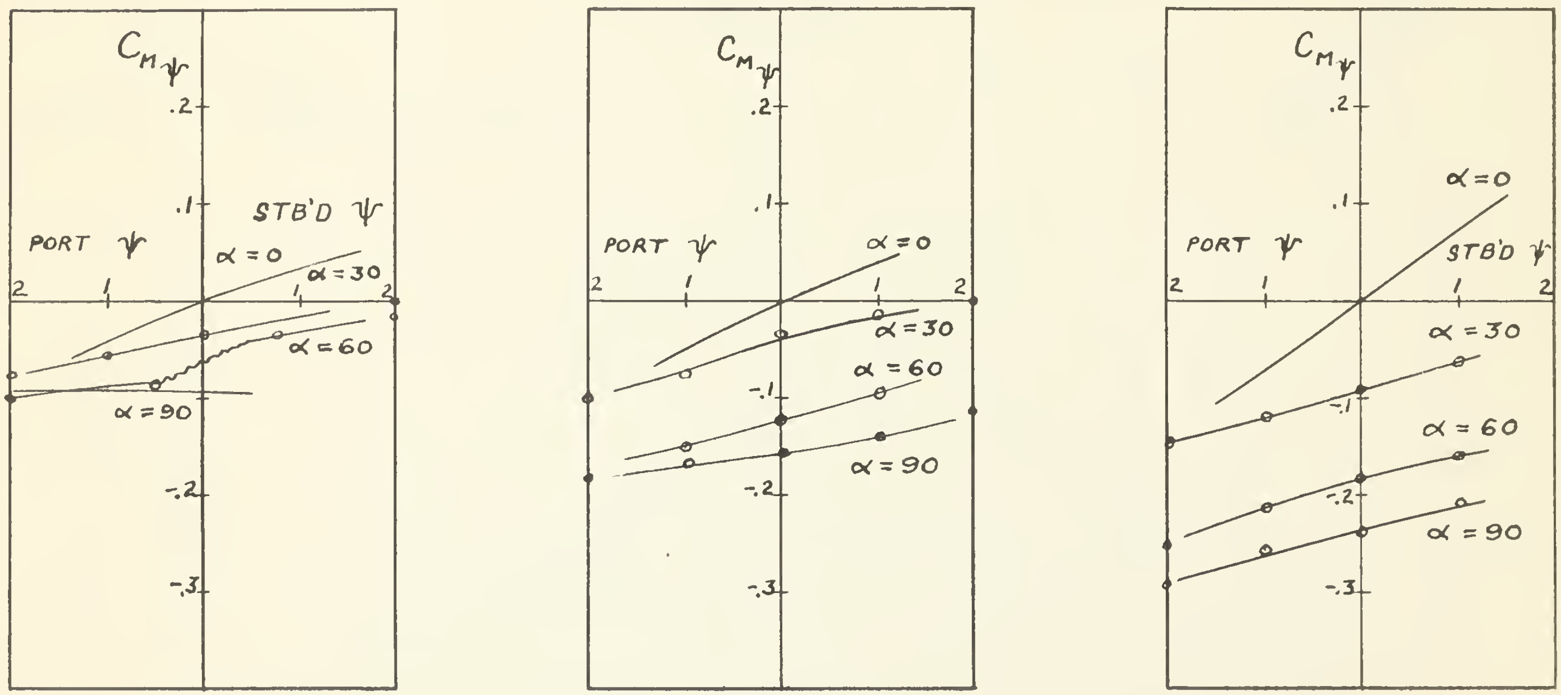
$C_v = 1.54$ $C_\Delta = 1.04$

$C_v = 2.02$ $C_\Delta = 0.99$

FIG. 12

C_{M_ψ} VS ψ DETERMINED BY EXPERIMENT

$\theta = 59°$



$C_v = 1.06$ $C_\Delta = 1.08$

$C_v = 1.54$ $C_\Delta = 1.04$

$C_v = 2.02$ $C_\Delta = 0.99$

FIG. 13

EXPERIMENTAL RESULTS FOR OPENING OF PORT HYDROFLAP $\psi = 0$

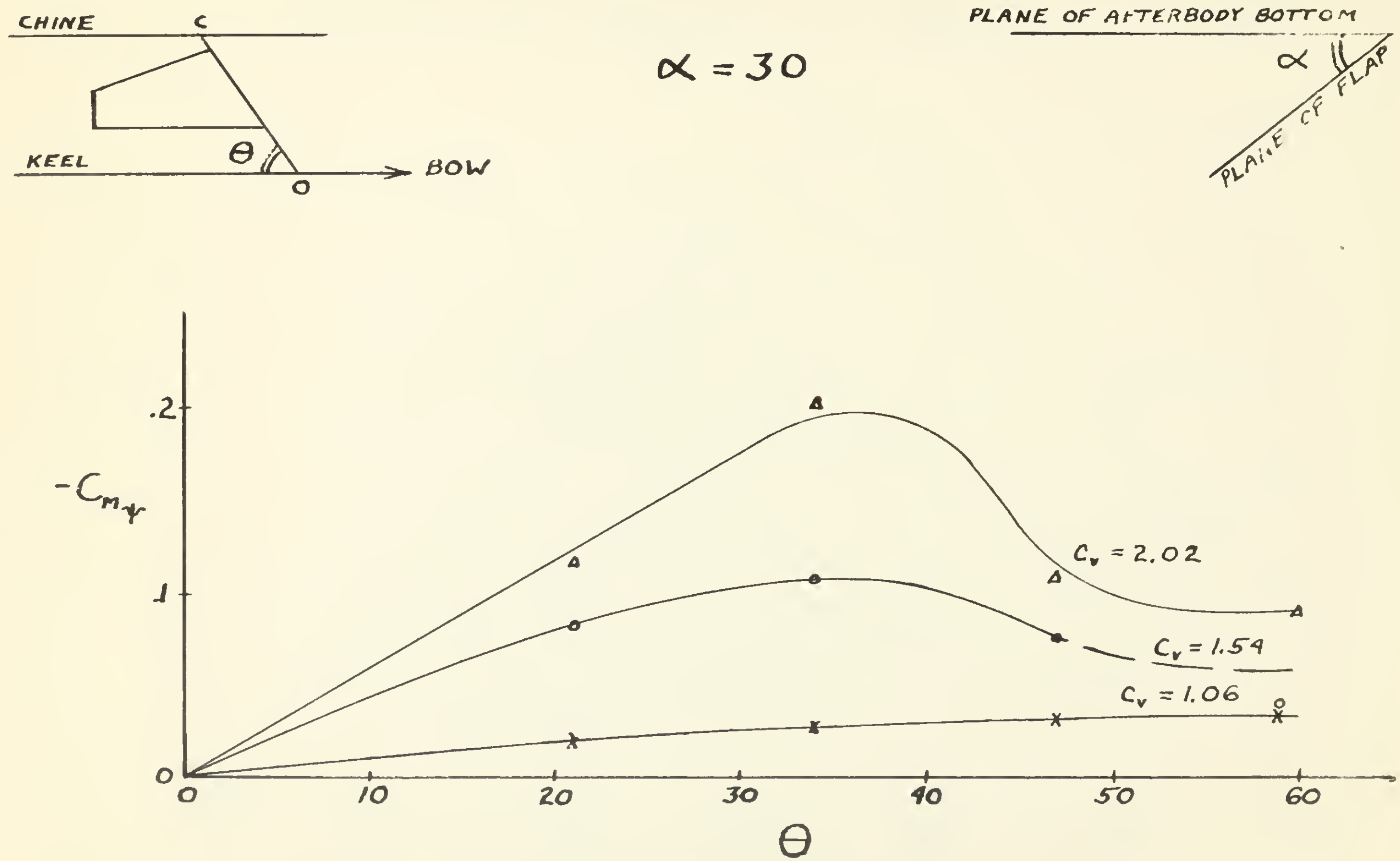


FIG. 14

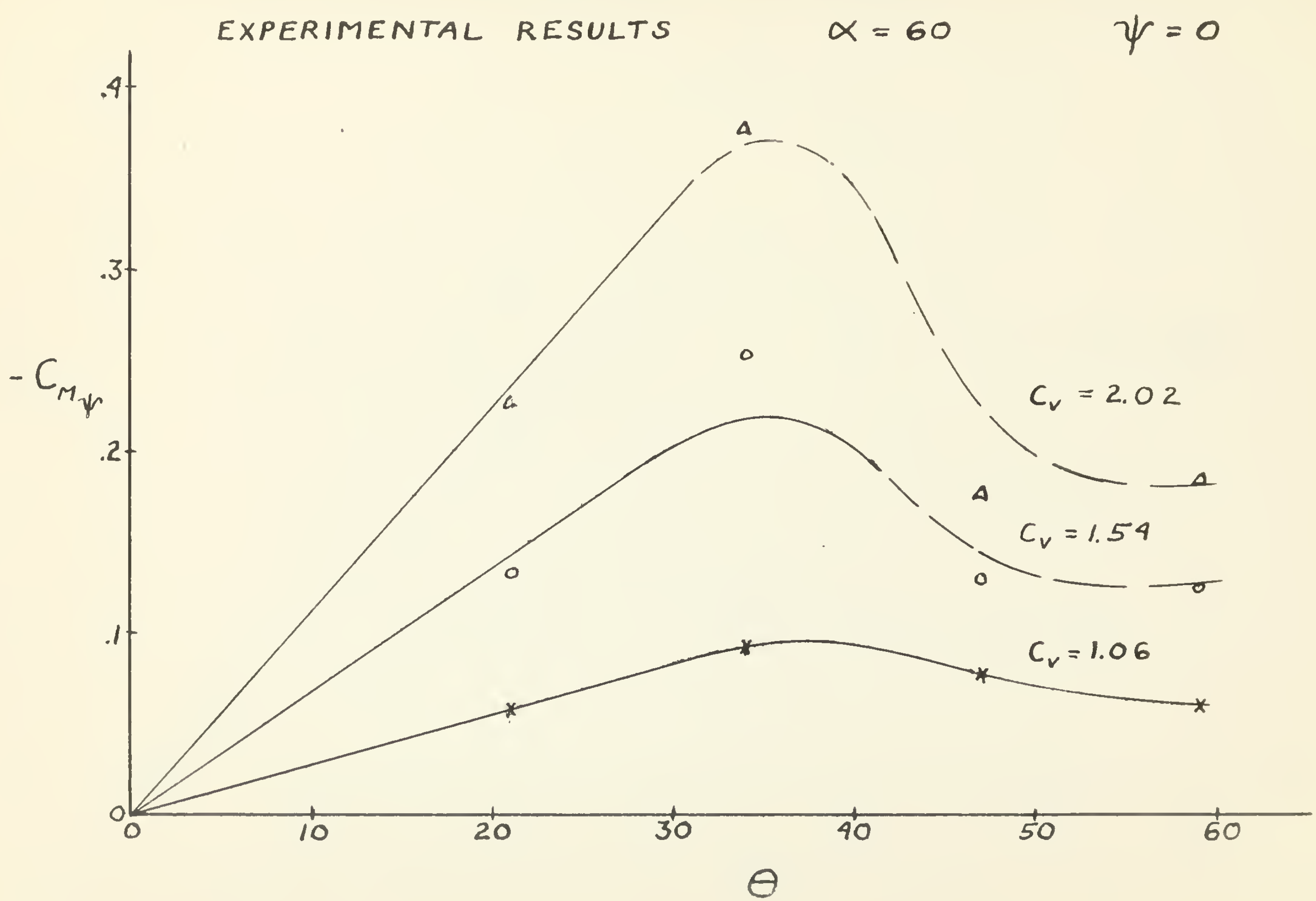

EXPERIMENTAL RESULTS
$\alpha = 60$
$\psi = 0$
$-C_{M_\psi}$
.4
.3
.2
.1
0
0
10
20
30
40
50
60
θ
$C_v = 2.02$
$C_v = 1.54$
$C_v = 1.06$

FIG. 15

EXPERIMENTAL RESULTS $\alpha = 90$ $\psi = 0$

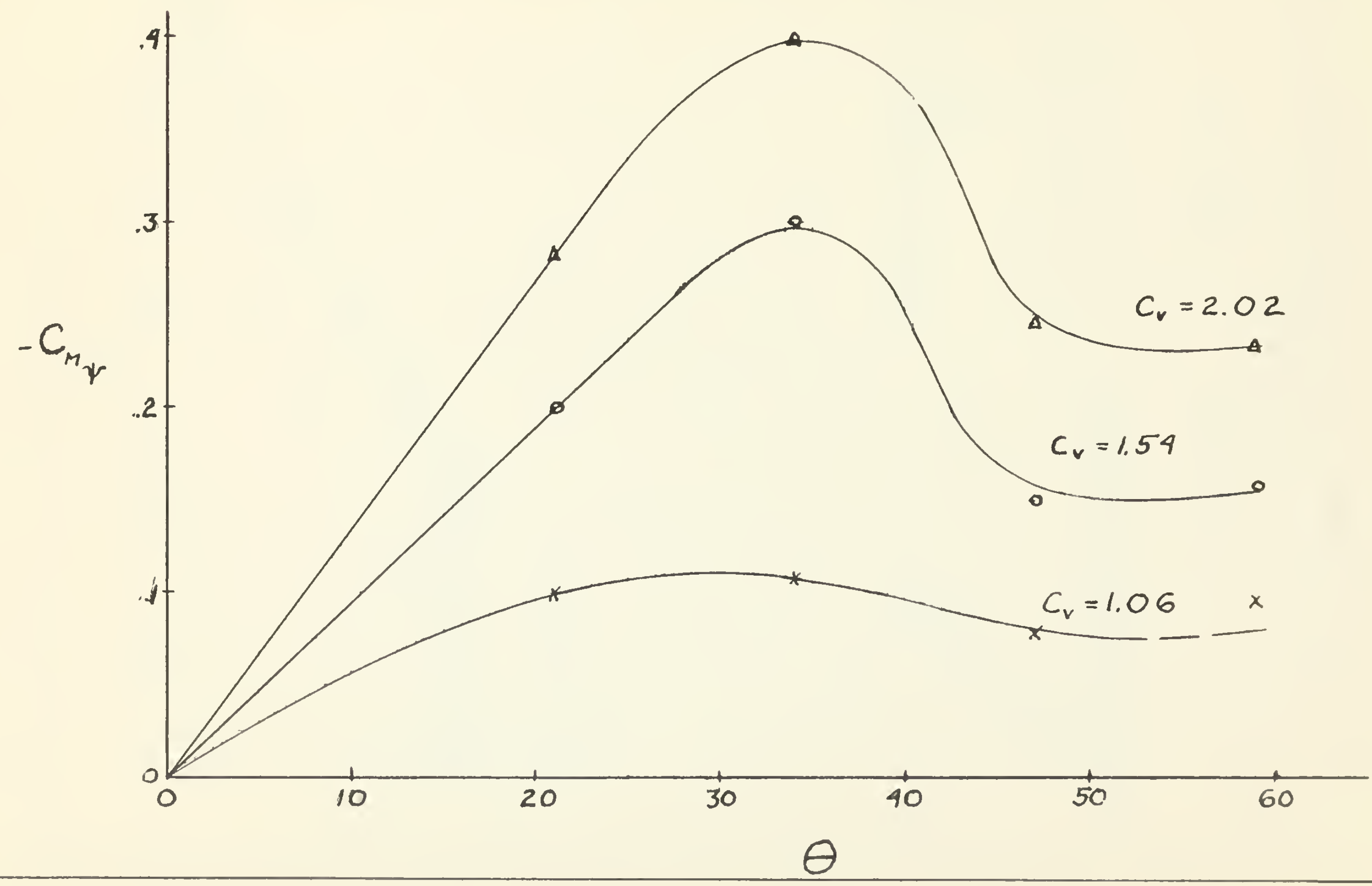
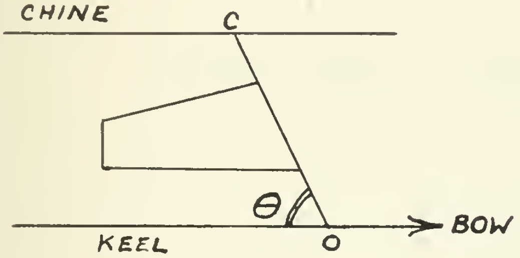
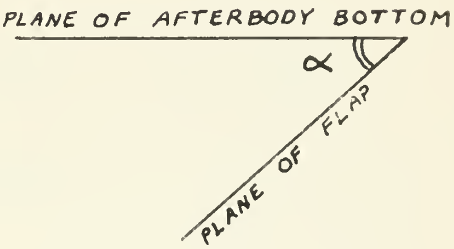


FIG. 16

EXPERIMENTAL RESULTS FOR OPENING OF PORT HYDROFLAP

$C_v = 1.06$ $\qquad \psi = 0$





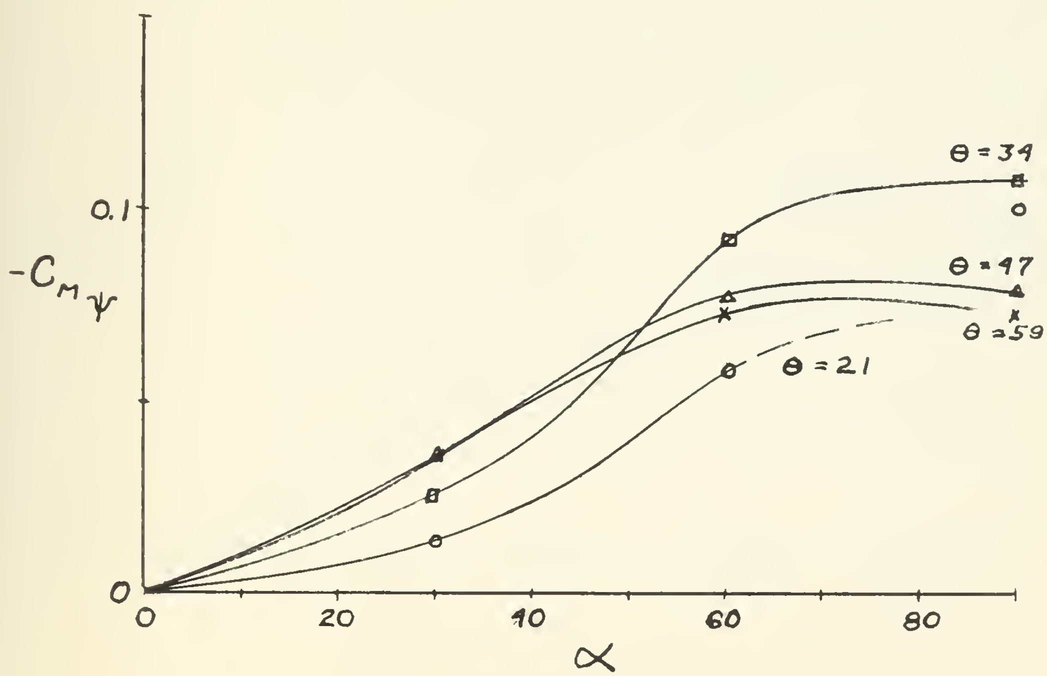


FIG. 17

EXPERIMENTAL RESULTS $C_v = 1.54$

$\psi = 0$

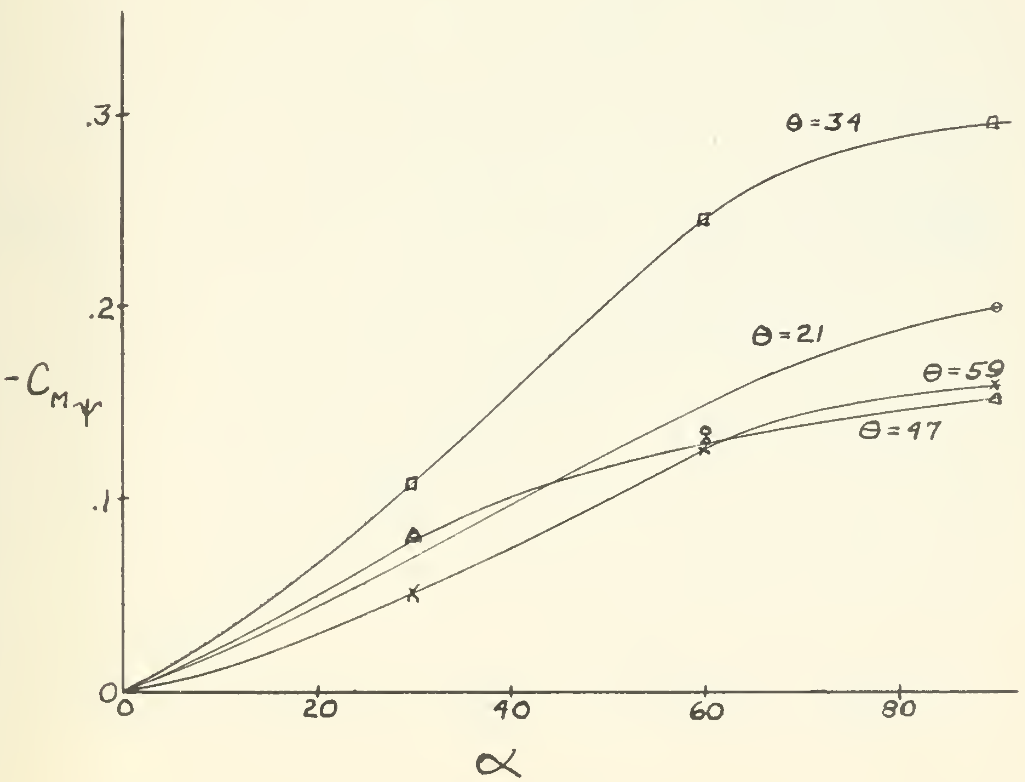


FIG. 18

EXPERIMENTAL RESULTS

$C_v = 2.02$ $\psi = 0$

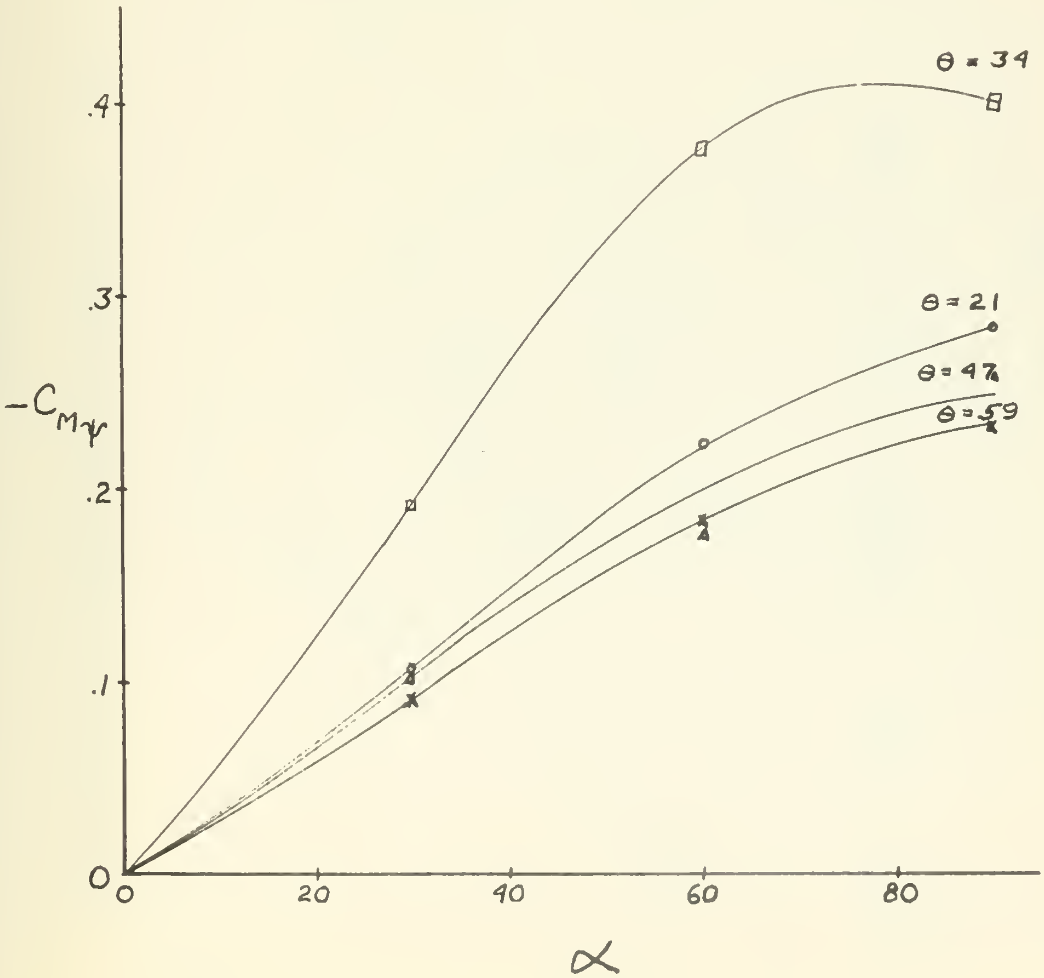
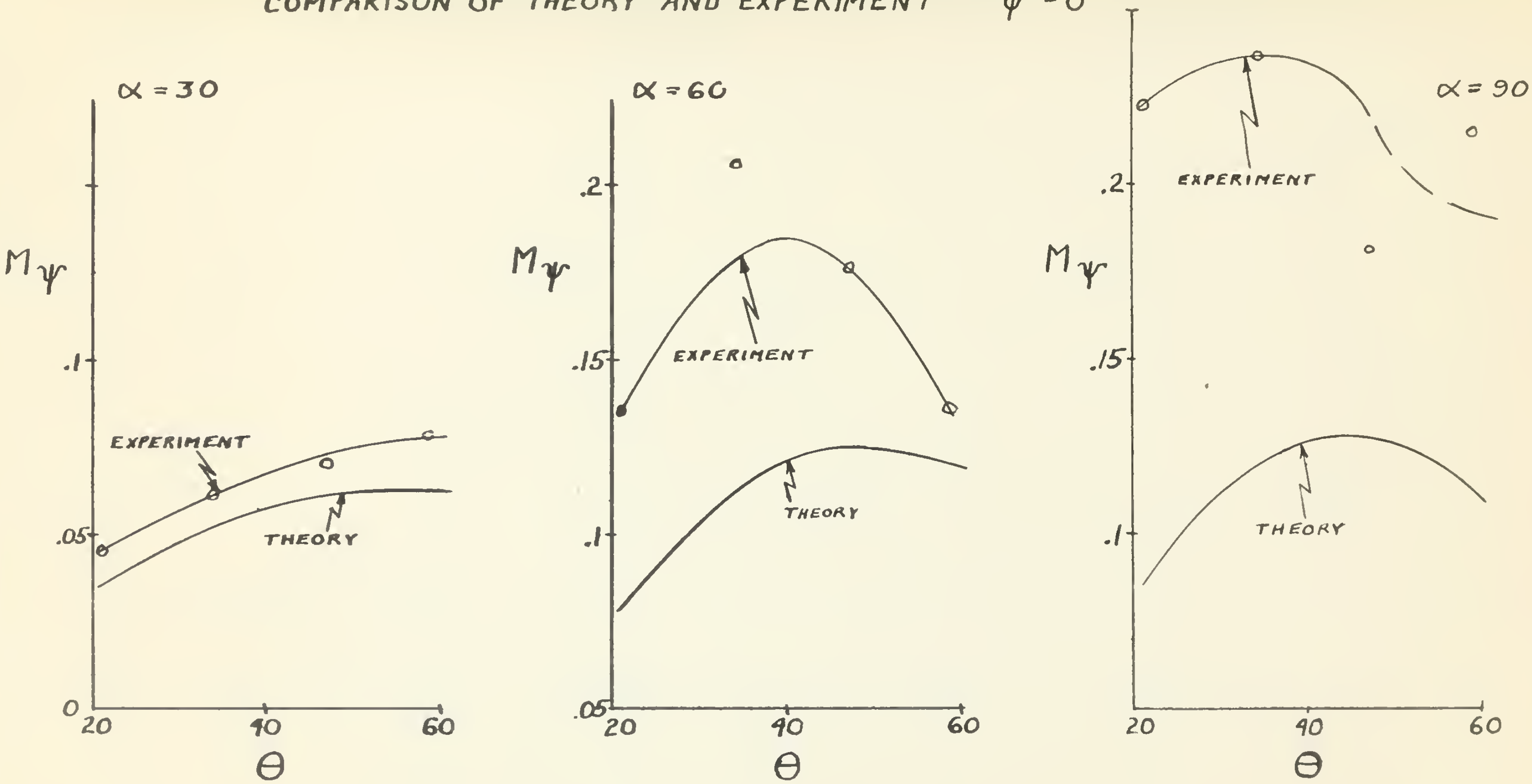


FIG. 19

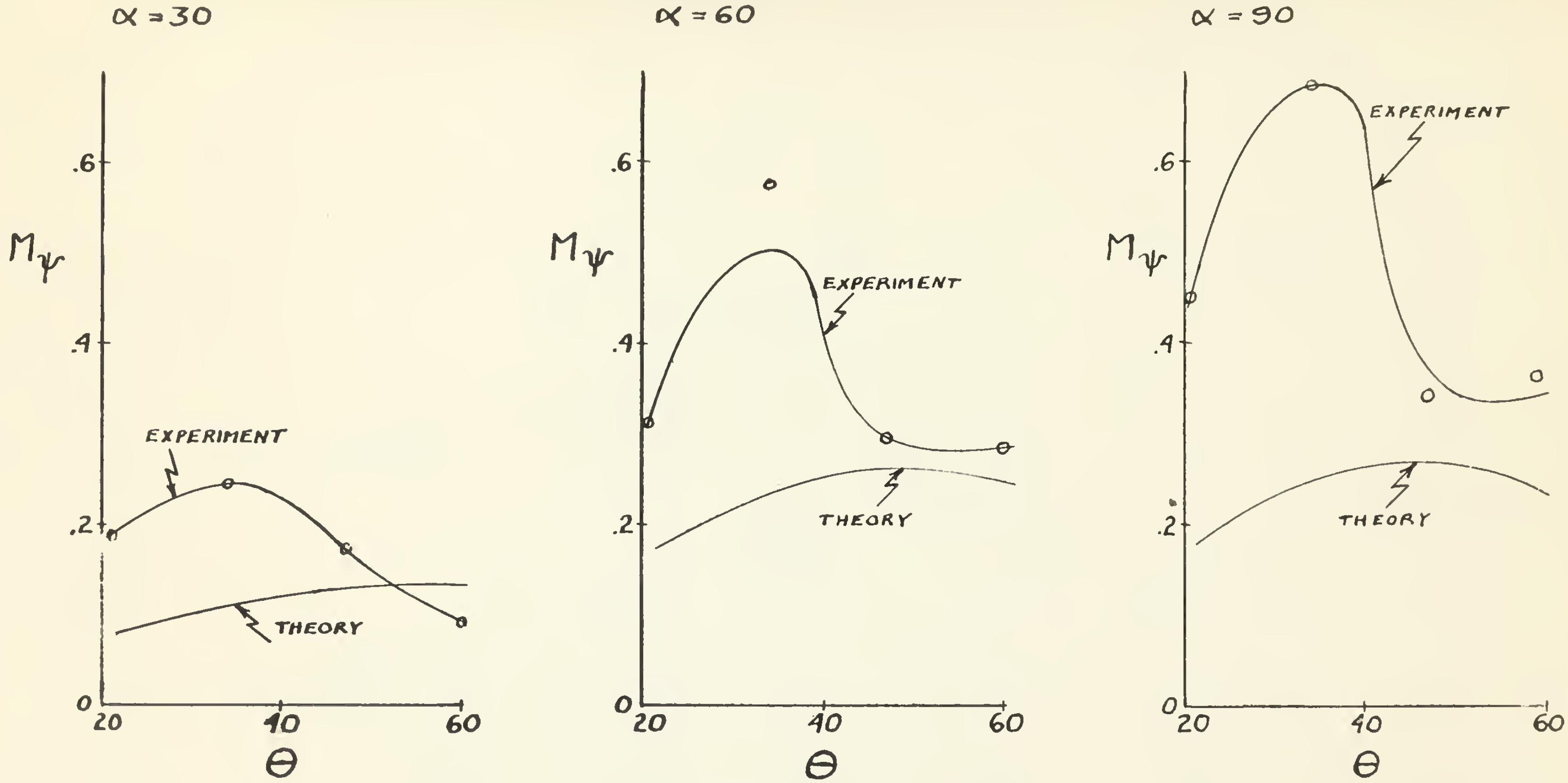
COMPARISON OF THEORY AND EXPERIMENT $\psi = 0$



$C_v = 1.06$

FIG. 20

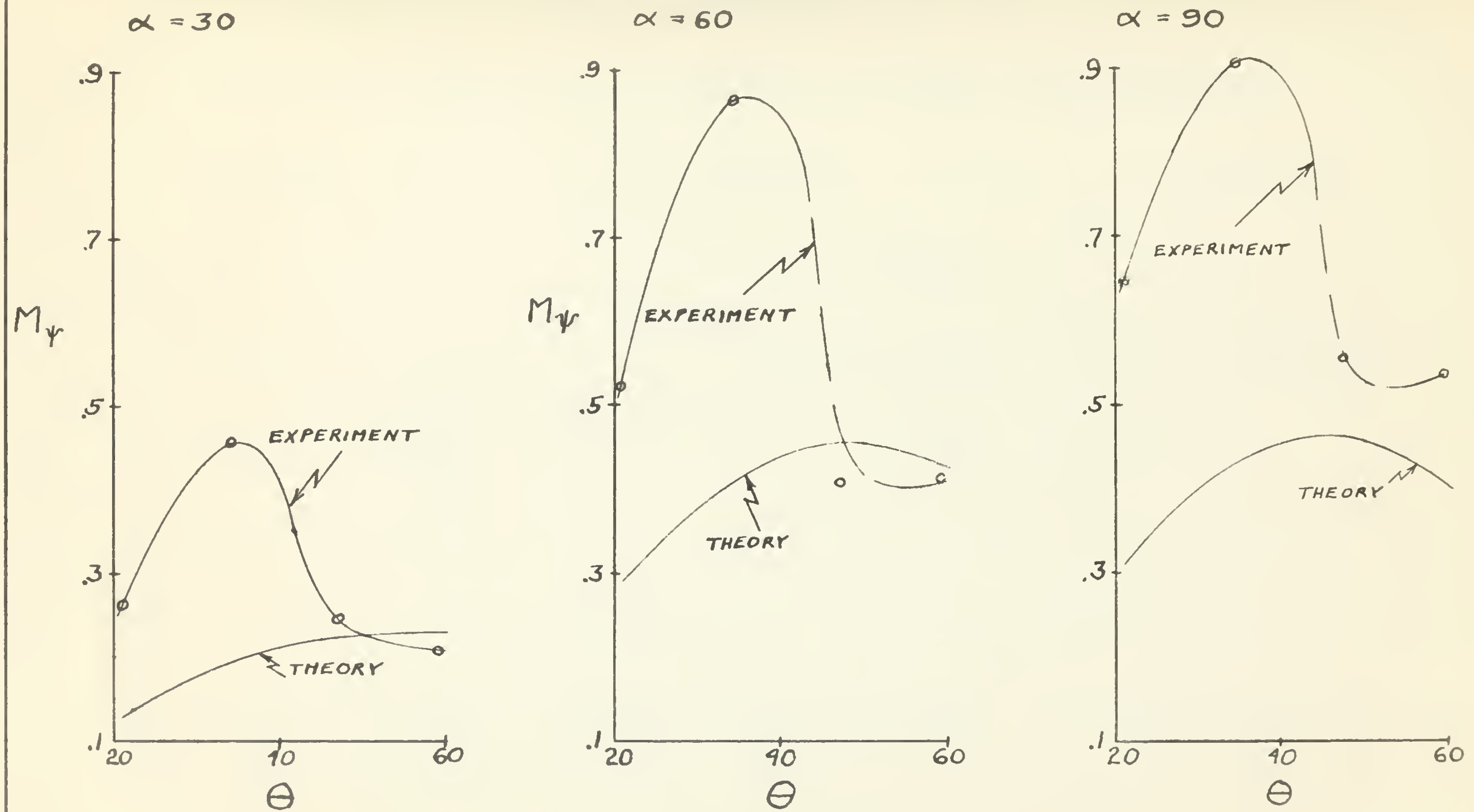
COMPARISON OF THEORY AND EXPERIMENT



$C_v = 1.54$

FIG. 21

COMPARISON OF THEORY AND EXPERIMENT $\psi = 0$



$C_v = 2.02$

FIG. 22

VALUES OF k DETERMINED BY COMPARISON OF THEORY AND EXPERIMENT

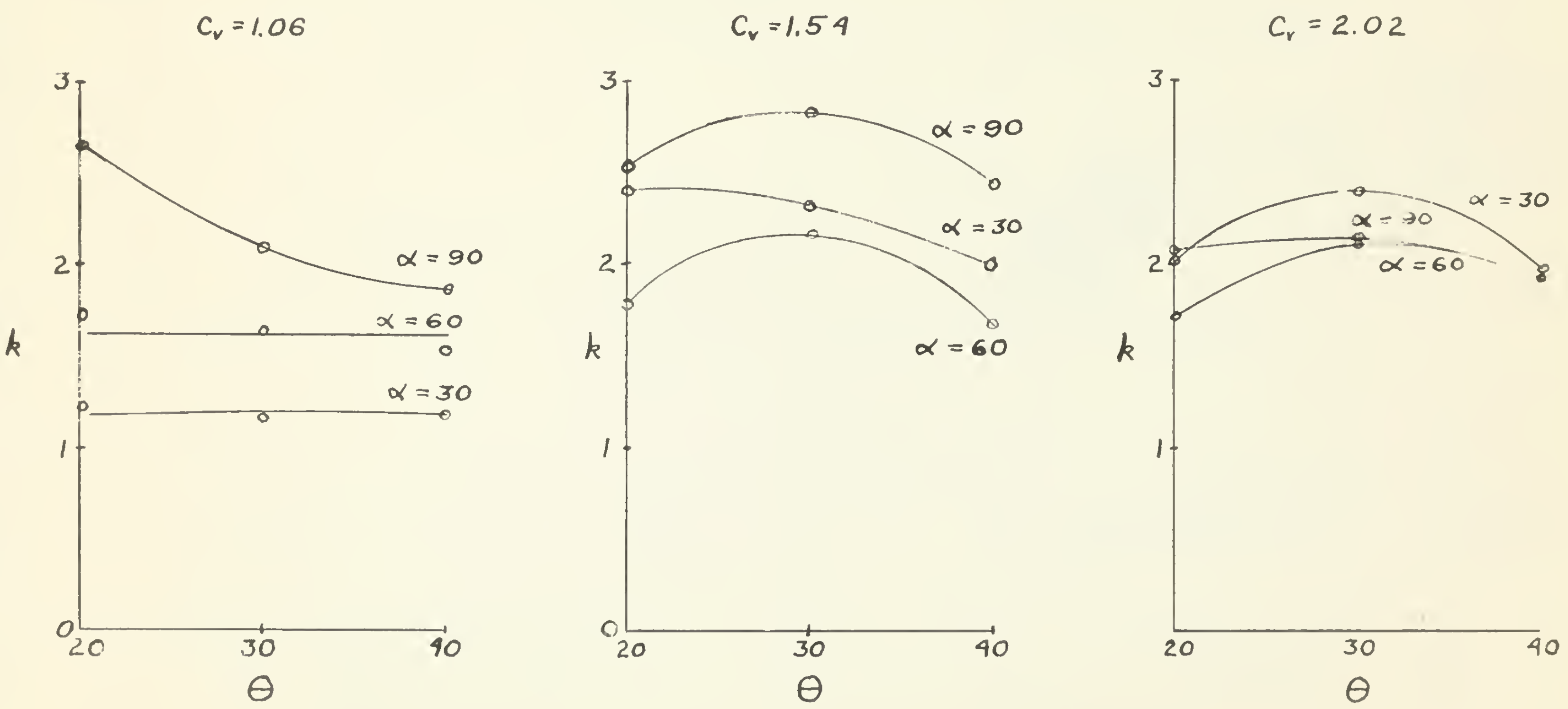


FIG. 23

AVERAGE VALUES OF k TAKEN FROM FIG. 22

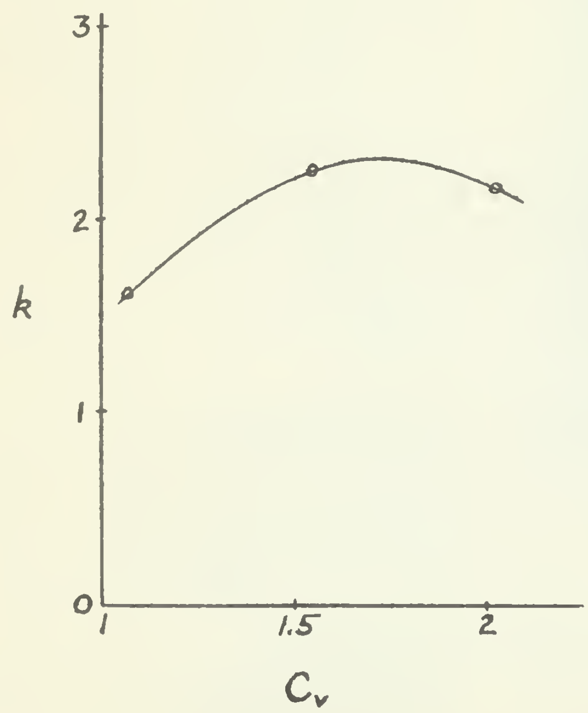


FIG. 24

PHYSICAL CONCEPT OF k FACTOR

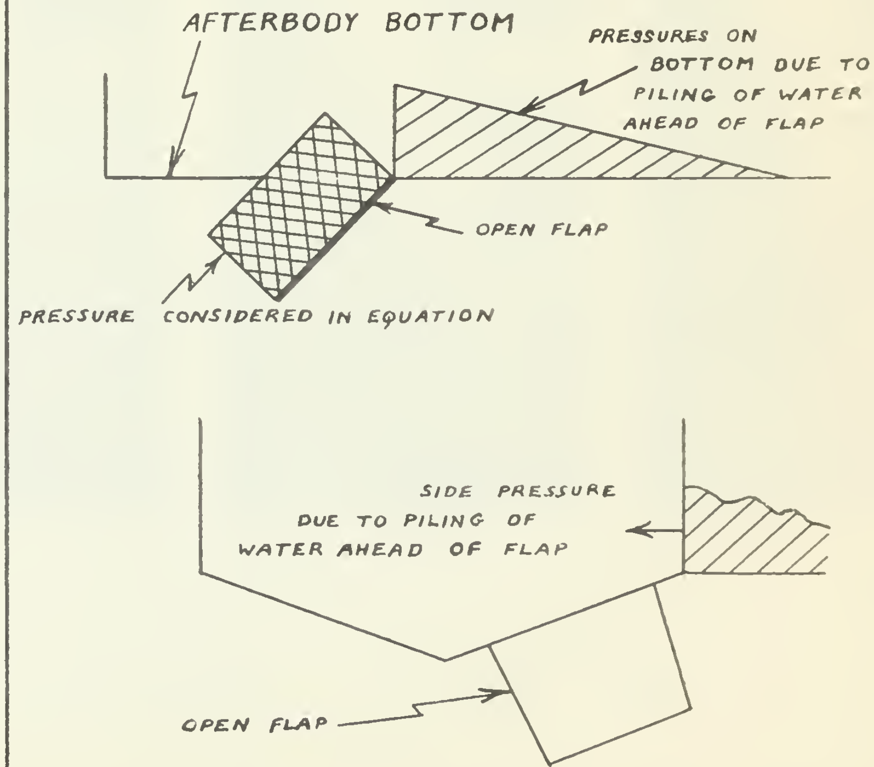


Fig 25

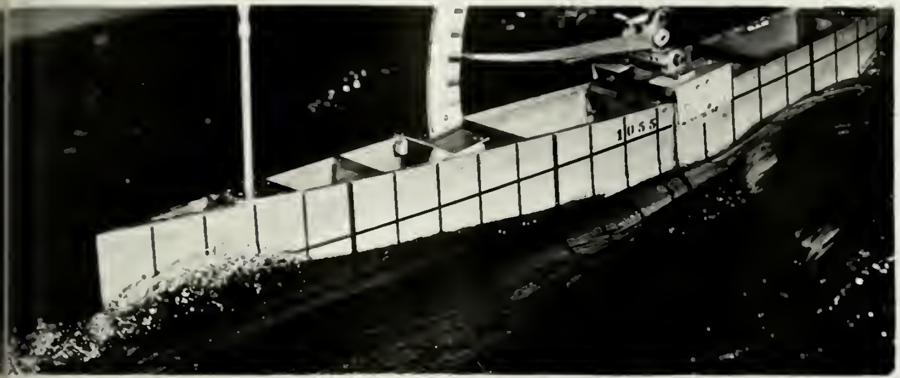
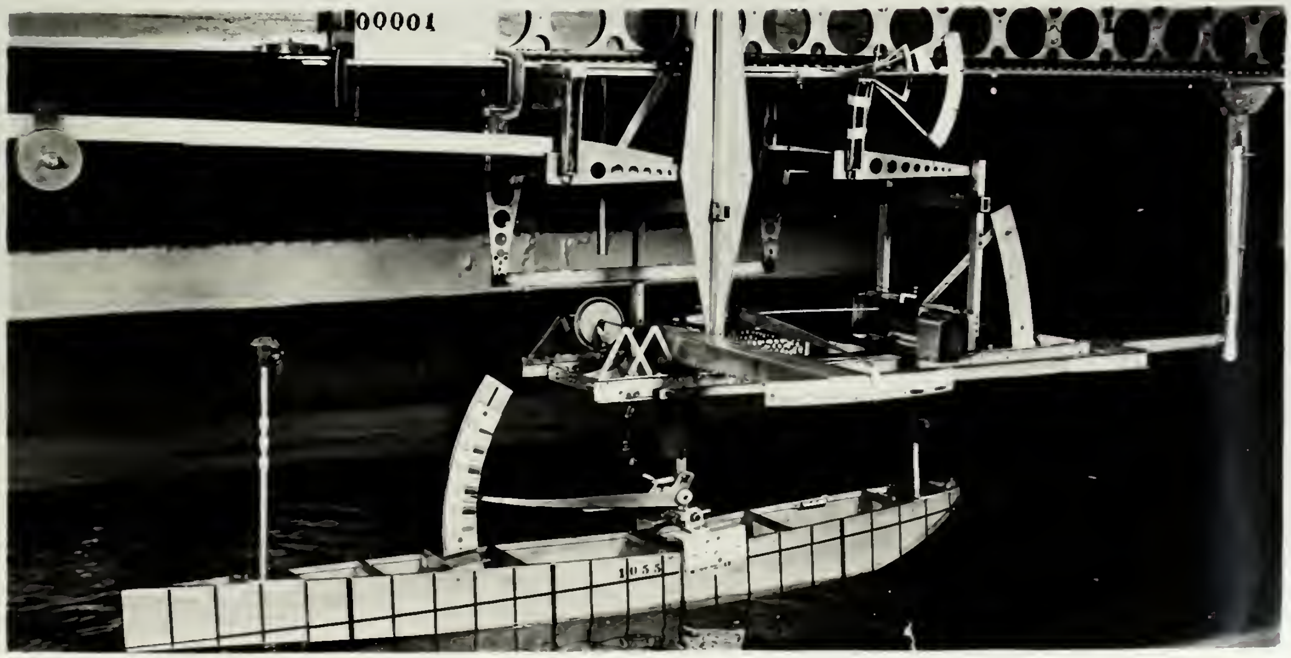


Fig 26

Fig 27

28



Thesis 17319
B33 Beck
An investigation of
hydroflaps for steering
seaplanes.

Thesis 17319
B33 Beck
An investigation of
hydroflaps for steering
seaplanes.

Thesis 17319
B33 Beck
An investigation of
hydroflaps for steering
seaplanes.

thesB33
An investigation of hydroflaps for steer
3 2768 002 12913 2
DUDLEY KNOX LIBRARY